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ABSTRACT

This minicourse, partially supported by the Division of Nuclear Education and Training of the U.S. Atomic Energy Commission, is an effort to describe the benefit-to-risk ratio of various methods of generating electrical power. It attempts to present an unbiased, straightforward, and objective view of the advantages and disadvantages of nuclear generation of electricity. Through reading and other activities, the student considers the generation of electrical energy, nuclear reactors, biological effects, waste products, plant sites, environmental impact, and costs. (CP)

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The Environmental Impact of Electrical Generation:

NUCLEAR vs. CONVENTIONAL

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PDE WORKING PAPER

Preliminary Edition

The Environmental Impact of Electrical Power Generation: Nuclear vs. Conventional

A Minicourse for Secondary Schools

Pennsylvania Department of Education
Bureau of General and Academic Education
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PURPOSE OF COURSE

In an era when the requirement for additional sources of power is growing at an ever-increasing rate, and concern for the protection of our environment is rightfully coming to the fore, it is imperative that an unbiased, straightforward, and objective view of the advantages and disadvantages of the nuclear generation of electrical power be made available to our schools.

The development of this minicourse has been partially supported by the Division of Nuclear Education and Training of the U.S. Atomic Energy Commission and produced under the direction of the Pennsylvania Department of Education. It was written and compiled by a committee drawn from educators, engineers, health physicists, members of industry and conservation groups, and environmental scientists.

This course is an effort to describe the benefit-to-risk ratio of the various methods of generation of electrical power.

THE ENVIRONMENTAL IMPACT OF ELECTRICAL POWER GENERATION PROJECT

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FOREWORD

The need for increased electrical generating capacity and the resulting environmental effects of meeting this need are of prime concern to all of us. The goal of *The Environmental Impact of Electrical Power Generation: Nuclear vs. Conventional* is to present a study of this problem in an informative, unbiased manner, allowing the student to gather pertinent information and draw his own conclusions.

For this reason the committee responsible for developing this study was selected from those possessing expertise in areas representing various aspects of the problem. The committee included educators, nuclear engineers, geologists, ecologists, fisheries biologists, physicians specializing in nuclear medicine, conservationists, and health physicists. Approximately 1,000 students in various parts of the state were polled in order to determine which aspects of this problem were of greatest concern.

The demand for power production is no longer met by traditional methods alone. The rising costs and decreased availability of fossil fuels have more than offset the major adjustments of the power industries including such examples as mine mouth operations and construction of plants with increased generating capacity. In addition, many years of research and development have not yet produced economical and effective methods of controlling the environmental damage of traditional power sources.

A rapid increase in nuclear generating capacity is occuring and will continue to occur at an increasing rate through our efforts to meet power needs. The related problems of thermal pollution, radioactive gas discharges, disposal of radioactive wastes, and the possibility of accidental exposure to radiation increase as this growth continues.

Opposition to nuclear power stations has increased. The average citizen is at a loss when he attempts to decide upon the benefit-to-risk ratio associated with nuclear generating stations. He is beset by opposing reports from conflicting interest groups concerned with the desirability or dangers of these facilities.

This is an unfortunate situation since it is better to have an informed public to influence decisions concerning solutions to this problem. This course provides a view of the need for increased power and the environmental price which we must be willing (or unwilling) to pay in order to fill this need.

This minicourse may be inserted into currently existing science or social studies courses, and in this way reach a great number of students in a relatively short time. It could also be offered as a short independent course to interested students or to adults as part of an evening school program. It is hoped that this course will have a lasting impact in producing a well informed citizenry capable of utilizing wisely their democratic franchise.

INTRODUCTION

Population growth, at the present rate, is something new under the sun. Modern medicine and sanitation have enabled more people to live longer and to have more children. However, rapid population growth is not new to American life. Big families are rooted in our frontier tradition - our early years of rapid growth westward - when families of seven or eight children were necessary for some to survive in a harsh and forbidding environment.

With the closing of the frontier American families became smaller, and during the Depression years the U. S. population began to decline. Following World War II the size of the American family again increased significantly.

This change in family size was accompanied by a change in the areas where people lived. At the turn of the 20th century, 40 per cent of the total population lived in cities and towns of more than 2500, but by the end of World War I half of the total population were living in communities of this size. In 1970, 70 per cent (140 million people) live in cities, towns or suburbs which cover less than 2 per cent of the land of the United States. Of this population, 40 per cent of the people live in 28 metropolitan areas which contain more than 1 million inhabitants.

This pattern was being reproduced over the world. Twenty-five per cent of the world's total population in 1960 lived in urban localities. This included more than half of the people of West Germany, the United States, New Zealand, Argentina, Uruguay, Chile and Israel.

Twelve per cent of the world's population lived in cities of more than 500,000. According to UN projections, by the year 2000 44 per cent of the world's population will live in urban areas.

Projected population of the United States in the mid-1970's could be 205.2 million. By 2040, the estimated population will have doubled to 410.4 million.

If this growth pattern continues, at least three quarters of the next hundred million persons will be located in highly urbanized areas. Their support will depend upon a limited amount of land, water, and air.

The factors that threaten our land, air and water are many and interdependent. The American population is growing fast. From 1950-62 the number of families increased by 20 per cent, but the number of car owning families increased by 60 per cent. These car owning families lived mainly in the cities. Their 60 million privately owned automobiles consumed 40 billion gallons of gasoline per year. The exhaust particles and gases were dispersed mainly in the cities because 93 per cent of all auto trips are entirely or partially within city limits. The annual exhaust emissions from this number of automobiles releases 11 million tons of hydrocarbons and 60 million tons of carbon monoxide. During the period from 1930 through 1950 air pollution was regarded as a nuisance but today it is accepted as a threat to the health and welfare of man. People and sources of air pollution tend to concentrate in the same places, which means in effect that the problem of air pollution presses hardest in our cities.

People and their automobiles in the cities are but a part of the total air pollution load present in the urban center. The growth of industrial production is accompanied by a demand for a myriad of services to satisfy the present wants of society.

As our population grows we pile up more garbage. To handle this waste more incinerators and land fills are needed, but only a limited amount of space remains. People, automobiles, goods and services all confined within the urban center produce pressures on all areas of our one and only environment.

The amount of electricity consumed in the United States is higher than in any other country in the world, and with every passing year the amount multiplies. In 1960, nuclear and hydroelectric energy, neither of which contribute significantly to air pollution, supplied a small fraction of our needs. Nuclear energy undoubtedly will be increasingly used in the future.

The principal fossil fuels used for steam electric power generation are bituminous coal, residual oil and natural gas, each with its own spectrum of air pollution. The combustion of fossil fuels annually produces some 142 million tons of air pollutants with power plants contributing 20 million tons, about 13 per cent of the total. For the individual pollutants, electric generating plants account for about 50 per cent of the sulfur oxides, about 20 per cent of the oxides of nitrogen and about 10 per cent of the emission of particulate matter.

Nuclear Power Plants

A principal area of concern is the growing use of nuclear power production facilities. About 20 nuclear plants are now operating in the United States, and this number is expected to increase to about 500 by the turn of the century. Strict regulations concerning the amounts of radiation which may be emitted into the environment by nuclear plants are in effect. Most plants discharge only about 1/100 of the allowed amounts. However, because the biological effects of low-level exposures to radiation have not been precisely determined, there is a controversy about the adequacy of existing standards.

Another area of concern is the possibility of a major accident in a nuclear plant with the accompanying release of high level radioactivity. Natural and engineered safeguards and the probability of such accidents will be discussed in later chapters.

The Power Problem

Student Activity:

On the form below list the electrical appliances found in your home. Do not forget such items as electric furnace blowers, light bulbs, electric fans, kitchen appliances, hair dryers and the like. Tomorrow you will calculate the annual kilowatt hour consumption in your home and the per capita annual kilowatt hour consumption for the members of your family.

Appliance	Annual KWH Consumption (from table)
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	
11.	
12.	
13.	
14.	
15.	
16.	
17.	
18.	
19.	

	Appliance	Annual KWH Comsumption (from table)
20.		
21.		
22.		
23.		
24.		
25.		

Total Annual Kilowatt-Hour Consumption

$$\frac{\text{Total Annual KWH Consumption for family}}{\text{Number of Persons in Family}}$$ per capital annual KWH consumption for my family.

Electrical Consumption of Some Common Home Appliances

Appliance	Estimated Annual KWH Consumption
Air Conditioner, Window	940
Bed blanket	147
Broiler	100
Carving Knife	8
Clock	17
Clothes Dryer	998
Coffee Maker	106
Deep Fat Fryer	83
Dehumidifier	377
Dishwasher	363
Fan, attic	291
Fan, circulating	43
Fan, furnace	450
Fan, window	170
Floor polisher	15
Food blender	15
Food freezer (15 cu. ft.)	1,195
Food freezer, frostless (15 cu. ft.)	1,761
Food mixer	13
Food waste disposer	30
Frying Pan	186
Grill, sandwich	33
Hair dryer	14

Heat lamp	13
Heat pump	16,003
Heater, radiant	176
Heating Pad	10
Hot Plate	90
Humidifier	163
Iron (hand)	144
Iron (mangle)	158
Oil burner or stoker	410
Radio	86
Radio-phonograph	109
Range	1,175
Refrigerator (12 cu. ft.)	728
Refrigerator (12 cu. ft. frostless)	1,217
Refrigerator-freezer (14 cu. ft. frostless)	1,828
Roaster	205
Sewing Machine	205
Shaver	18
Sun Lamp	16
Television (B & W)	362
Television (Color)	502
Toaster	39
Tooth brush	5
Vacuum Cleaner	46
Waffle Iron	22
Washing machine, automatic	103

Washing machine, non-automatic	76
Water Heater, standard	4,219
Water Pump	231

If you know the amperage rating of any appliance, you can calculate the KWH Consumption by using the formula:

$$KWH = \frac{\text{Amps.} \times 110 \times \text{hours of use}}{1000}$$

Now that you have calculated the annual electrical consumption for your family, it must be pointed out that this only represents part of your per capita consumption. Much more electricity is expended to manufacture the goods and services which you require to maintain your standard of living. Most of the manufactured items which you take for granted - such as plastics, aluminum soft drink cans, glass jars, in fact every manufactured item, is made wholly or in part with the expenditure of electrical energy.

The per capita electrical consumption in the United States for the year 1968 was 6,500 kilowatt hours. Most of this was for industrial processes which maintain our high standard of living. The United States is one of the nations using a disproportionate share of the world's energy output, as well as a large share of other natural resources. According to the *New York Times* every child born in the U.S. will use eight times as much of the world's natural resources as a child born in an underdeveloped country.

Another factor contributing to the problem is the growth of our power demands. Our need for increased electrical output doubles every ten years.

By the turn of the century it is projected that the world population will reach 7 billion, and that 42 per cent of these persons will live in cities of over 100,000. Providing power for their living needs will place a heavy burden on the environment. But only 1/7 of the projected increase in electrical production in the U.S. will be due to this population increase. Most will be due to industrial processes and improved transportation required to maintain an ever increasing standard of living. If all the projected plants were coal fired, by 1980 we would need 800 million tons of coal per year, which would require 250,000 additional coal cars to transport this coal to power plants and return to the mine. At present the total number of coal cars in the U.S. is 205,000. This need for fuel would double by 1990 and double again by 2,000.

If all these projected plants were gas-fired, by 1980 we would need 19,200 billion cubic feet of gas. The total production of gas in the U.S. in 1967 was 18,171 billion cubic feet.

If all these projected plants were oil-fired, by 1980 we would need 3.35 billion barrels of oil. The total U.S. production of oil in 1967 was 3.217 billion barrels.

Another factor to consider is that coal and oil are non-renewable natural resources. We will deplete our supply in the foreseeable future. Even our known reserves of high-grade uranium ore will support large scale power production for only another 25 to 50 years. There is hope that breeder reactors, which produce more fissionable material than they consume, will offset any uranium shortage for some years to come. However, the technology to develop efficient breeder reactors is only now reaching the pilot plant stages, and the first generation of these reactors is about to be built.

The most probable resolution to this dilemma will be found in the development of methods to utilize a process called fusion. This is the process which powers the sun. In fusion two light nuclei are fused together to form a heavier nucleus. The essential fuels in this reaction are lithium and heavy hydrogen. The energy which could be produced by the fusion of the deuterium nuclei present in a gallon of ordinary water is equal to that obtainable from the combustion of 300 gallons of gasoline. The enormous amounts of water available on earth makes this process a nearly inexhaustable fuel supply. The cost of extracting the deuterium from water is comparatively low. So here may be the ultimate fuel - cheap, abundant, and available to all.

However, tremendously difficult problems must be solved before the generation of power from fusion can become a reality. The solutions to these problems are most likely many years in the future. But we must have energy in increasing amounts until that future day when fusion may solve all of our energy needs.

The following tables will help clarify this information.

Table I

Estimated Depletion of Fuel Reserves.

Fuel	Year
Mineable Coal:	2400
Oil:	2030
Gas:	2080
Fission: (High grade ores)	2000
Breeders:	4000
Fusion:	5000 (?)

Table 2

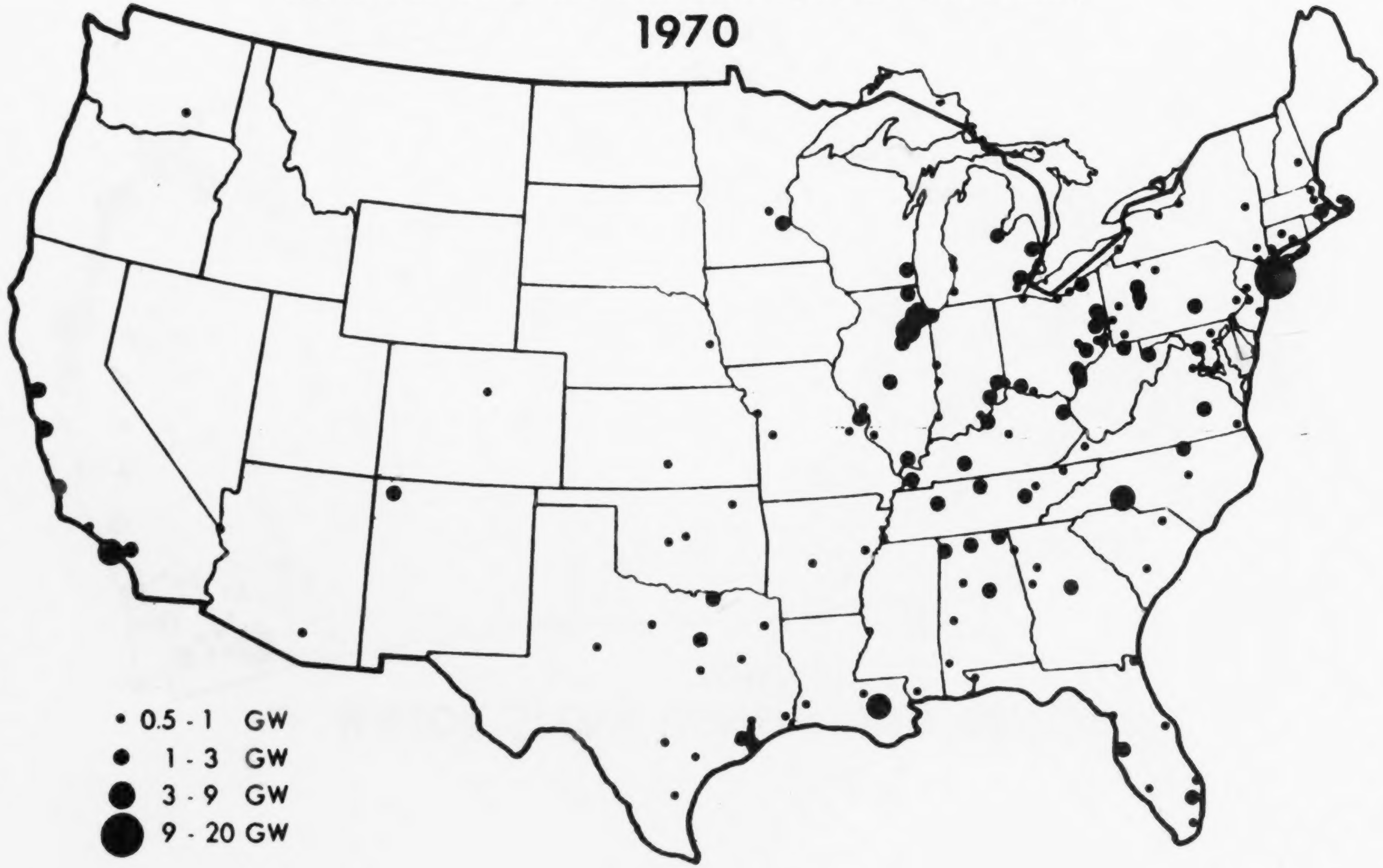
Population Projections and Power Needs

These projections were compiled by the electric utility industry as a reasonable estimate on which to base future requirements.

	1950	1970	1980*	2000*
U.S. Population (millions)	152	206	232	301
Total Power Capacity (millions of kilowatts)	85	340	665	2,100
Power Consumed per person per year (kilowatt - hours)	2,000	7,000	13,000	33,000
Nuclear Power Capacity (millions of kilowatts)	0	7.5	150	1,100
Nuclear Power Capacity (% of total power capacity)	0	2%	22%	50%

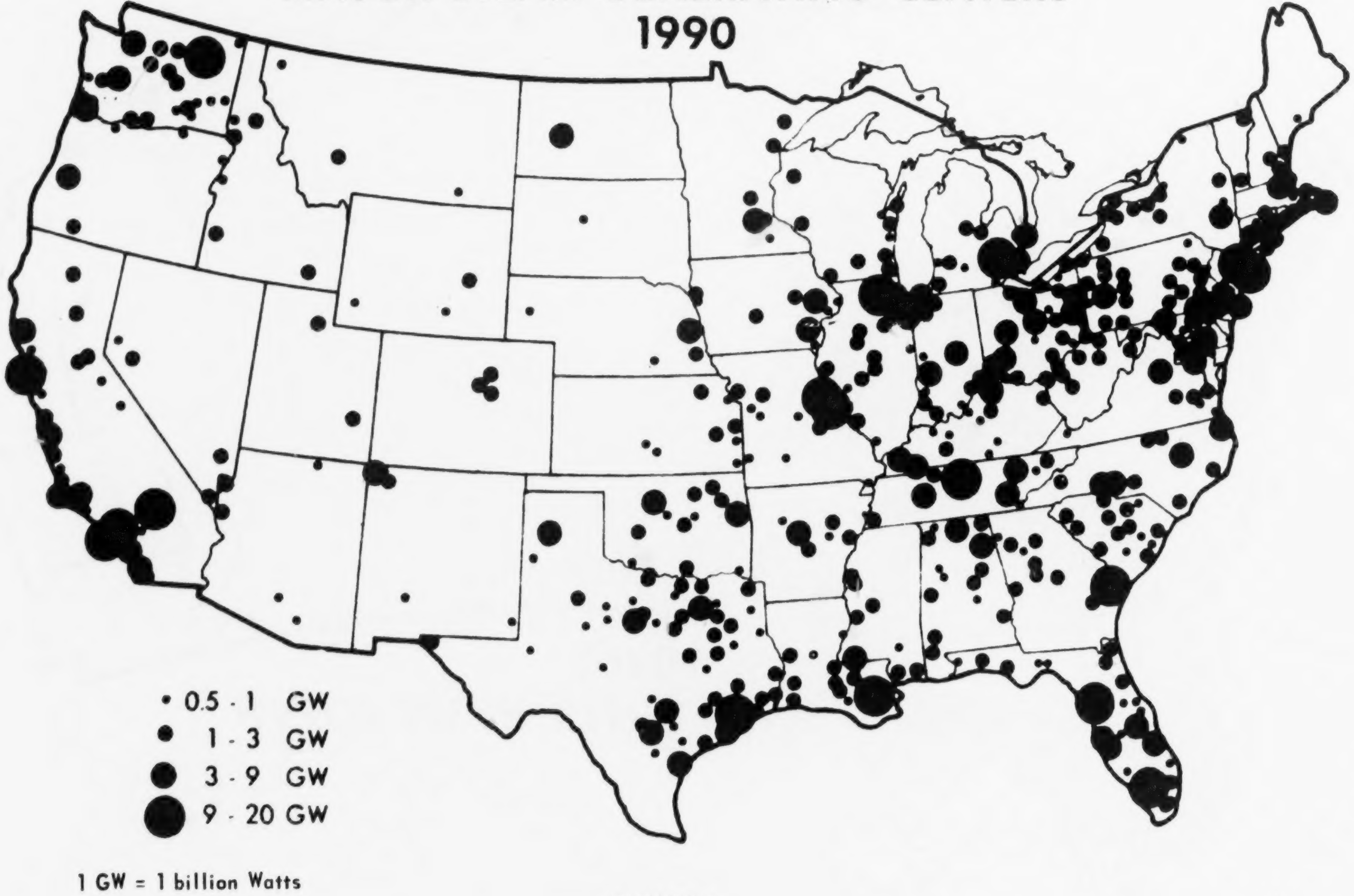
*Projected

MAJOR STEAM GENERATING CENTERS
1970


• 0.5 - 1 GW
● 1 - 3 GW
● 3 - 9 GW
● 9 - 20 GW

1 GW = 1 billion Watts

FIGURE 1



MAJOR STEAM GENERATING CENTERS
1990

• 0.5 - 1 GW
● 1 - 3 GW
● 3 - 9 GW
● 9 - 20 GW
1 GW = 1 billion Watts

FIGURE 2

CHAPTER I

THE GENERATION OF ELECTRICAL ENERGY

Among the materials most familiar to us, metals are the best conductors of electricity. This results from their being made up of atoms having electrons which are relatively free to move from one atom to another.

In 1808 Oersted discovered how these electrons could be made to move in a length of wire and in so doing he created a flow of electrons which we have come to call an electric (electron) current.

Creation of a small electric current (flow of electrons) in a wire is done quite simply. The materials needed consist of a strong magnet, a loop of wire, and a force to move the wire loop through the field which exists between the north (N) and south (S) poles of a magnet. In the diagram below we see a loop being pulled through the magnetic field lines of force (dotted lines) which causes an electric current to flow in the directions of the arrows associated with (A) and I.

If the stick figure were to suddenly turn around and push the loop in the opposite direction, the current would also change direction.

If we rotate a loop of wire rapidly in a magnetic field as shown in diagram 2 below, the current changes direction with each rotation and an alternating current (a.c.) is produced. The flow of electrons changes directions as many times as the loop is rotated.

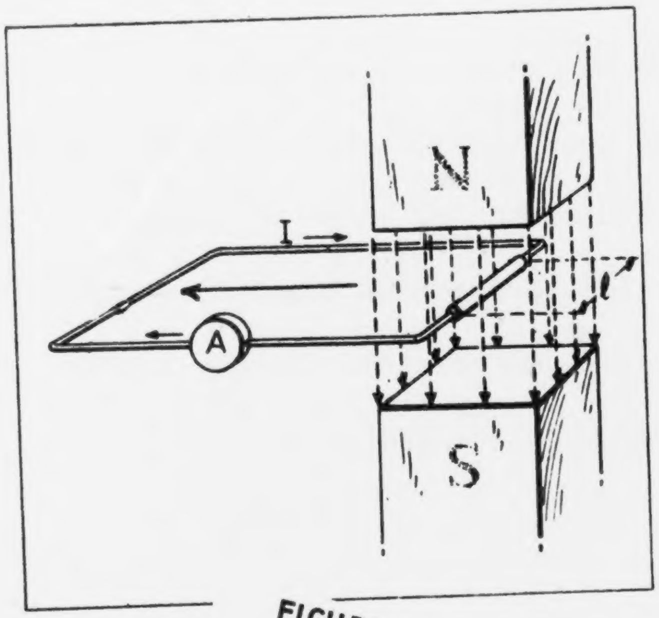


FIGURE 3

When a wire loop is pulled sideways through a magnetic field, a current flows in the loop.

Commercial electric generators operate on the same basis as our single loop of wire but they contain many loops of wire and many magnets. In addition a force is needed to rotate the many loops rapidly in a magnetic field.

Our story about the production of electricity begins at this point.

Most electricity is produced by using heat to convert liquid water to steam. The steam provides the force used to rotate a turbine which operates a generator containing loops and magnets, and in which an electric current is produced.

Steam generating systems to rotate the turbines use gas, oil, coal or a nuclear reactor to convert the liquid water to steam. Shown below is a flow of diagrams for a power station using coal. Although the heat values shown in BTU's would be different if gas, oil or uranium were used, the remainder of the diagram would be the same.

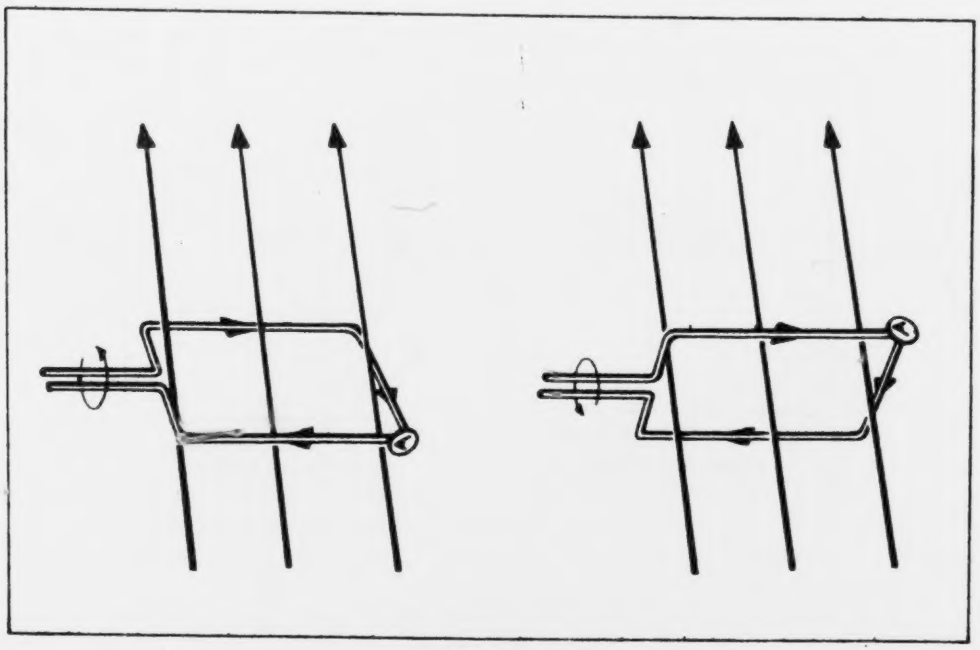


FIGURE 4

When a loop of wire is rotated in a magnetic field, an alternating current is produced in the loop.

In the diagram it can be seen that from 8,540,000 BTU produced by burning coal, only about 40 per cent or 3,415,000 BTU end up as mechanical energy to operate the generator. A sizable loss of heat energy - 3,845,000 BTU - occurs as the *"spent"* steam from the turbine, is cooled and condensed to liquid water.

If we combine the heat losses to air and water as shown in the diagram, we see that 60 per cent of the heat energy produced in a fossil fuel power station is lost to the environment.

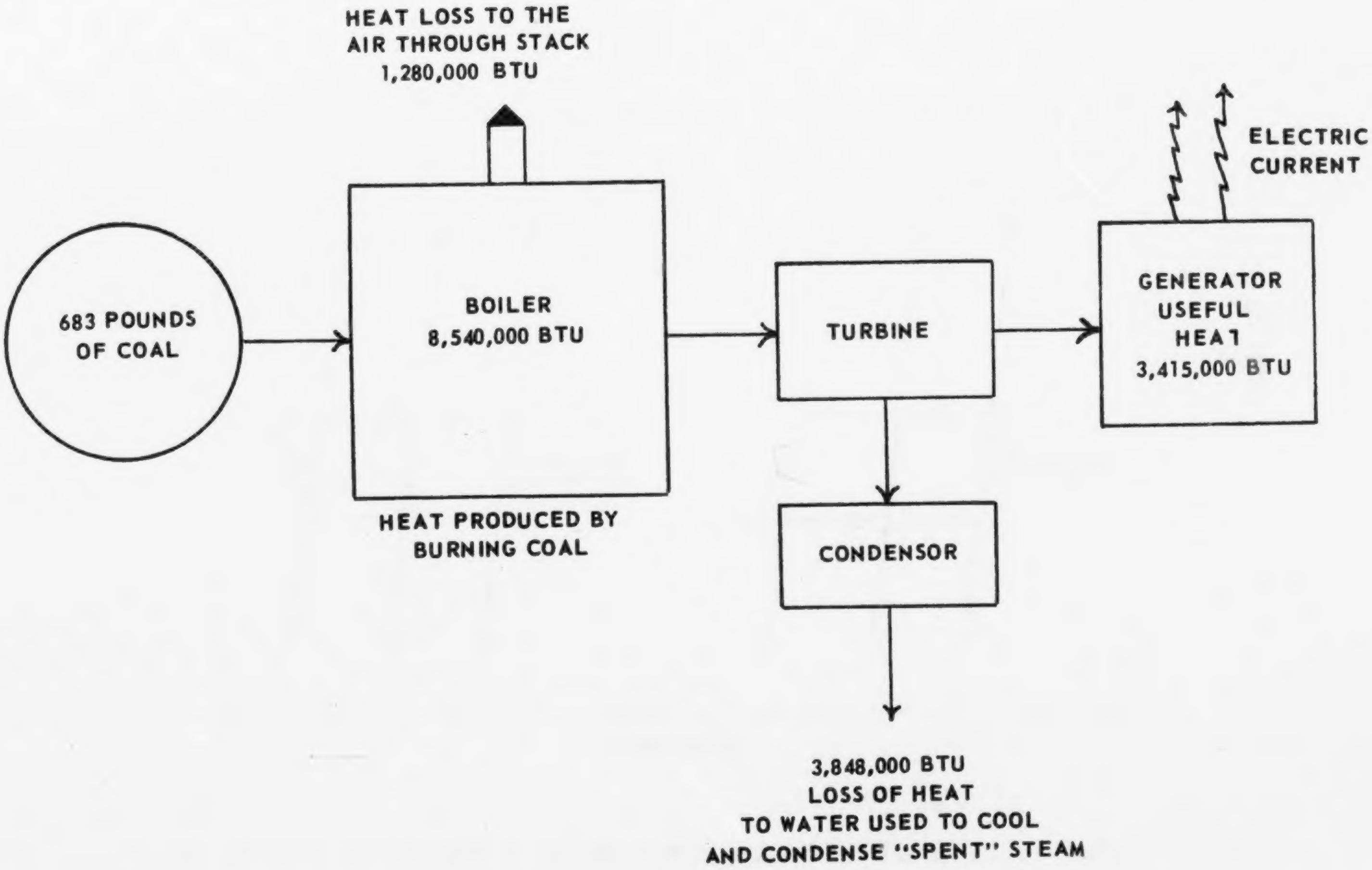

HEAT LOSS TO THE
AIR THROUGH STACK
1,280,000 BTU
ELECTRIC
CURRENT
683 POUNDS
OF COAL
BOILER
8,540,000 BTU
HEAT PRODUCED BY
BURNING COAL
TURBINE
GENERATOR
USEFUL
HEAT
3,415,000 BTU
CONDENSOR
3,848,000 BTU
LOSS OF HEAT
TO WATER USED TO COOL
AND CONDENSE "SPENT" STEAM

FIGURE 5

CHAPTER 2

NUCLEAR REACTORS

A nuclear reactor provides heat for power generation by the splitting or fission of a heavy atom rather than the burning of fossil fuels. For continuous heat generation a chain reaction is necessary. To obtain a chain reaction enough fuel must be packed close enough together to maintain a critical mass. While many designs are used, the non-breeding nuclear reactor has a safety advantage in being explosion proof but presents a hazard in incidental radiation and the formation of radioactive byproducts following the fission events. While no large inventory of fuel is needed for operation, periodic partial refueling is needed, and the used fuel must be reprocessed, creating an environmental problem. However, in a nuclear installation the contamination is localized and contained.

The Fission Process:

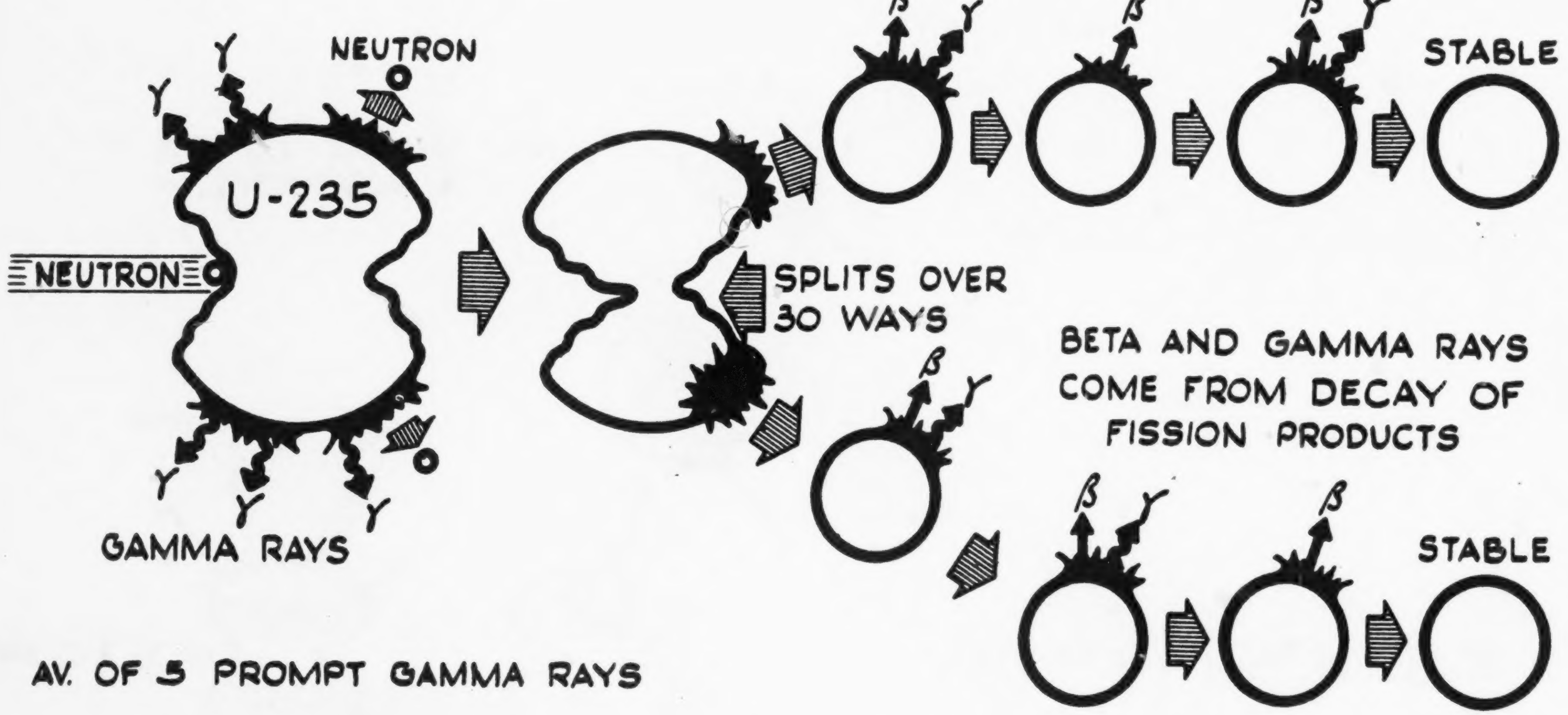
When atoms of certain heavy elementstypes are struck by neutrons, a neutron is sometimes captured by the atom. This atom then becomes unstable and will change in one of several ways. One of these ways is that the atom splits into two or more smaller atoms (fission fragments), releasing energy in the form of heat and radiation. Several free neutrons are also released, which may repeat this process in the nuclei of other atoms. This splitting is known as fission. The heat from this fission reaction can be used to boil water to make steam. This steam may be used to generate electricity just as in conventional power plants. Both Uranium-233 & Uranium-235 and Plutonium-239 tend to fission when struck by neutrons, and so are used as fuels in nuclear reactors.

The neutrons given off by the fissioning of one atom are available to strike other atoms, causing them to fission. This is the chain reaction. If the chain reaction is to continue, there must be enough atoms packed close enough together to insure the capture of enough neutrons to keep a constant rate of fission. The amount of material required for this is called the critical mass. (See Figures 6 and 7).

Some atoms that will not fission frequently change to smaller atoms by giving off small particles and/or energy at a defintie rate. This is known as radioactive decay and is one of the major sources of radiation hazard in the operation of a nuclear reactor. In time these atoms will have broken down and will no longer be radioactive. The time required for one-half of the radioactive atoms of an element to decay to stable atoms is known as the half life of that element. If an atom has a short half life it will quickly decay away. The smaller atoms produced by the fission process may also be radioactive, and if so will undergo decay.

Most of the radioactive materials formed in a reactor remain in the reactor but some are gaseous and must be removed. Fortunately most of these gases are of short half lives and can be held until they become stable before discharged into the atmosphere, or removed mechanically from the exhaust gases.

Uranium Fission Process


NEUTRON
NEUTRON
U-235
γ
GAMMA RAYS
SPLITS OVER 30 WAYS
β
STABLE
STABLE

BETA AND GAMMA RAYS COME FROM DECAY OF FISSION PRODUCTS

AV. OF 5 PROMPT GAMMA RAYS

AV. OF 2.5 NEUTRONS
(99% PROMPT, 1% DELAYED)

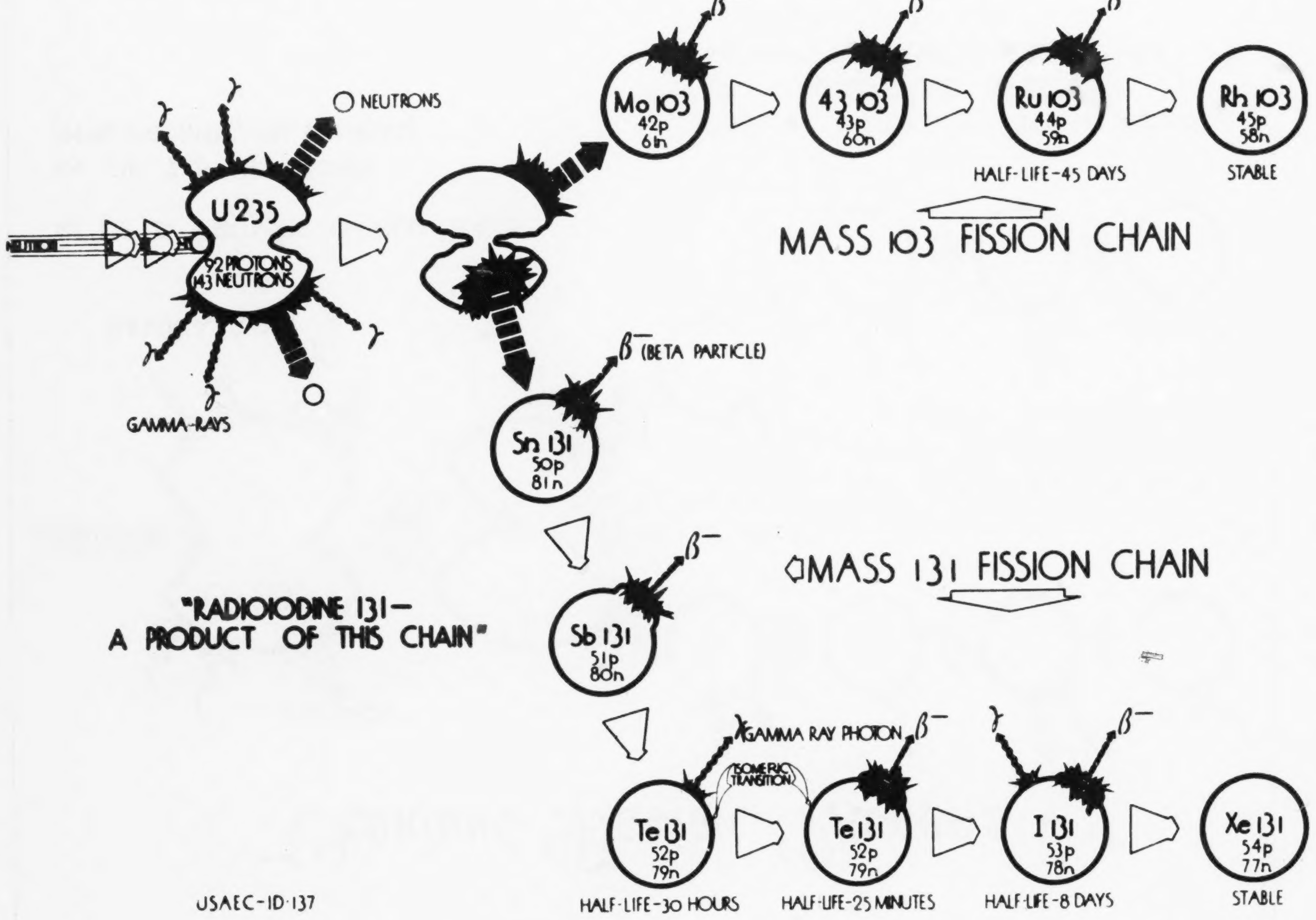
- FISSION PRODUCTS TOTAL ABOUT 200 RADIOACTIVE SPECIES.
- ATOMIC NUMBERS 30 TO 64
- MASSES 72 TO 161
- (Zn 72 TO Gd 161)

USAEC-ID-322A

FIGURE 6

USAEC Division of Technical Information Extension, Oak Rid

URANIUM FISSION AND BETA CHAIN DECAY


NEUTRONS
U 235
92 PROTONS
143 NEUTRONS
GAMMA-RAYS
γ
β^- (BETA PARTICLE)
Mo 103
42p
61n
43 103
43p
60n
Ru 103
44p
59n
HALF-LIFE-45 DAYS
Rh 103
45p
58n
STABLE
MASS 103 FISSION CHAIN
β^-
Sn 131
50p
81n
Sb 131
51p
80n
"RADIOIODINE 131 —
A PRODUCT OF THIS CHAIN"
MASS 131 FISSION CHAIN
GAMMA RAY PHOTON
ISOMERIC TRANSITION
Te 131
52p
79n
HALF-LIFE-30 HOURS
Te 131
52p
79n
HALF-LIFE-25 MINUTES
I 131
53p
78n
HALF-LIFE-8 DAYS
Xe 131
54p
77n
STABLE

USAEC-ID-137

FIGURE 7

Reactors

A reactor serves to contain and control the chain reaction. Different designs have evolved as a compromise between the need to maintain the critical mass and the need to remove the heat from the reactor for power production.

Certain parts are common to all reactors regardless of the reactor design. These parts include the fuel assembly, moderator, coolant, control rods, radiation shield and biological shield.

The *fuel assembly* itself is generally made up of bundles of fuel elements which individually are below critical mass. When several bundles of rods are assembled and a source of neutrons is inserted, a critical mass is reached and the chain reaction starts.

The *moderator* is a material between the fuel rods which serves to slow down the neutrons as they emerge from the fissioning atoms. This is necessary because neutrons travelling too fast are less readily captured and do not cause more fissions. Graphite, water or heavy water are commonly used moderators.

The *coolant*, either liquid or gas, flows over the fuel rods, removing heat from the fuel. The coolant does not come in contact with the actual fuel, since the radioactive material itself is sealed within the fuel rods.

The *control rods* are made of materials that readily absorb neutrons. These rods are usually strips of metal (boron or cadmium), positioned inside the fuel assembly. If the rods are pulled out of the bundle, more neutrons are available to cause fissioning of the fuel, so the rate of reaction increases. If the rods are inserted into the fuel bundle, there are fewer neutrons available to the fuel, so the chain reaction slows or may be stopped completely. This makes it possible to produce heat at a desired rate or to shut down the reactor completely.

Shielding

Components made of special materials surround different portions of the reactor system to prevent radiation from escaping into the environment. Some components reflect stray radiation back into the reactor. Others soak up radiation to protect important structural members from radiation damage. Still other shielding components prevent radiation from escaping and causing biological damage.

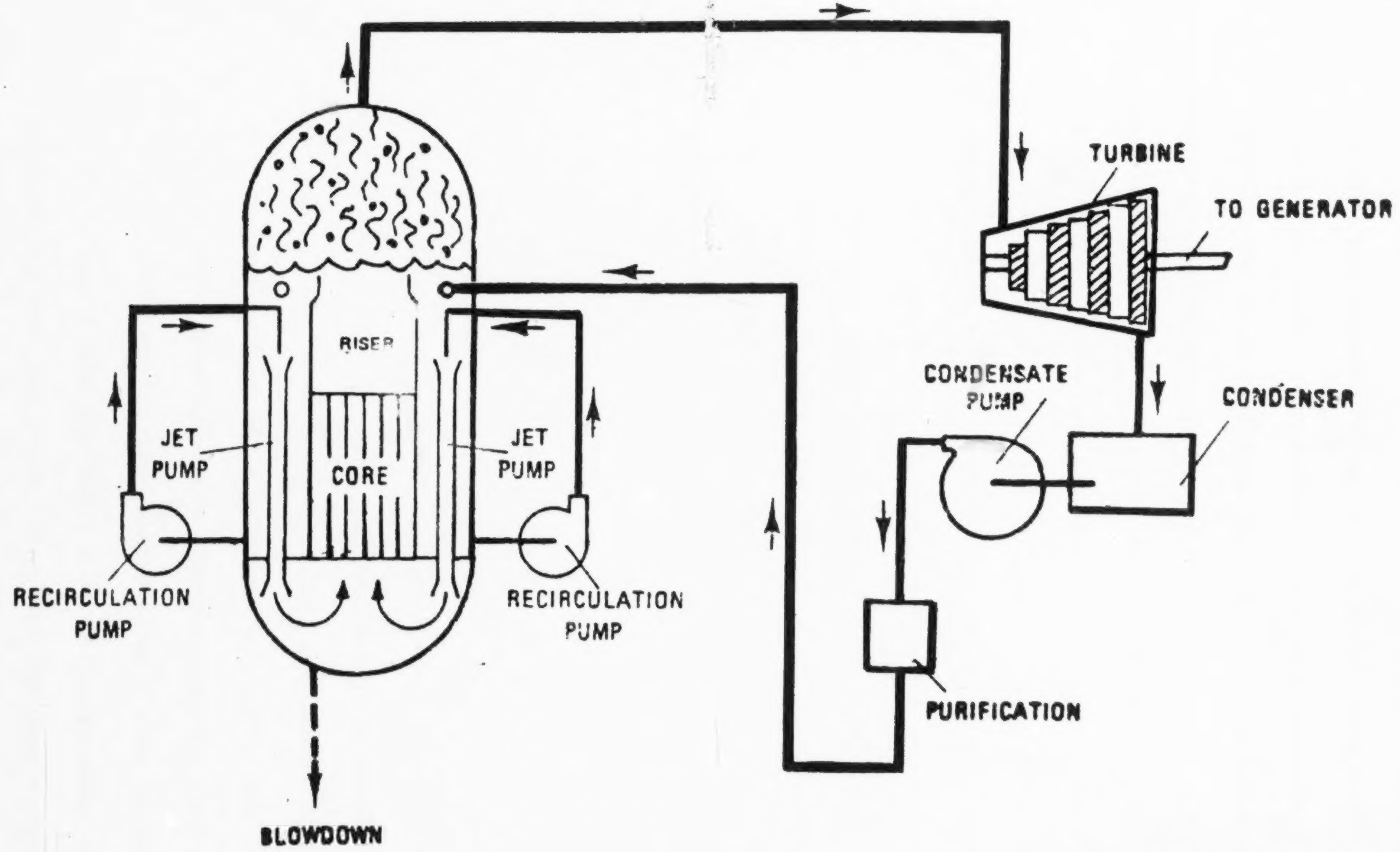
In many designs one of the reactor parts may serve to complement the others. For example, the cladding of the fuel rods may act as a reflector shield, and the coolant in some reactors also serves as a moderator. Many combinations like these have been developed, each of which has certain advantages and disadvantages. The more common types of reactors are boiling water reactors, pressurized water reactors, gas cooled reactors, heavy water reactors, and breeder reactors.

Boiling Water Reactors (BWR)

In the *Boiling Water Reactor* water is used as the coolant and serves a secondary function as the moderator and reflector. The water is brought into the reactor and allowed to boil. It then is taken out of the reactor as pressurized steam. The steam is used to drive a turbine producing electrical power. Typically a B.W.R. operates at about 1000 pounds per square inch and produces steam at about 550 °F. The B.W.R. has the advantage of simplicity, but suffers from the disadvantage of requiring a large core for cooling purposes. Some of the atoms and materials dissolved in the water may become radioactive and be carried through to the turbine section, thus increasing the area where a radiation hazard exists. The early models of boiling water reactors suffered from a high emission of radioactive gases as compared with other reactors, but this has been mostly eliminated in newer models. Boiling Water Reactors emit more radioactive gases than pressurized water reactors.

Pressurized Water Reactors (PWR)

In a pressurized water reactor system the water does not boil because of pressure. Instead it is pumped through the core and is removed at the top as a superheated liquid. The water is then circulated through a heat exchanger in which steam is produced and used to drive a turbine. The cooled water is then returned to the reactor to again cool the core. The PWR normally operates at pressures of 2000 pounds per square inch and about 600 °F. The P.W.R. has several advantages over other reactor types. The coolant used at the reactor core does not come into contact with the steam used to drive the turbine. Thus the turbine area remains uncontaminated with radioactive materials. The higher pressure allows more efficient heat transfer and requires a smaller surface area for the core. The P.W.R. however requires additional heat exchangers, and the high temperature increases the corrosion of the fuel rods, the cladding, and the vessel.


TURBINE
TO GENERATOR
CONDENSER
CONDENSATE PUMP
PURIFICATION
RISER
CORE
JET PUMP
JET PUMP
RECIRCULATION PUMP
RECIRCULATION PUMP
BLOWDOWN

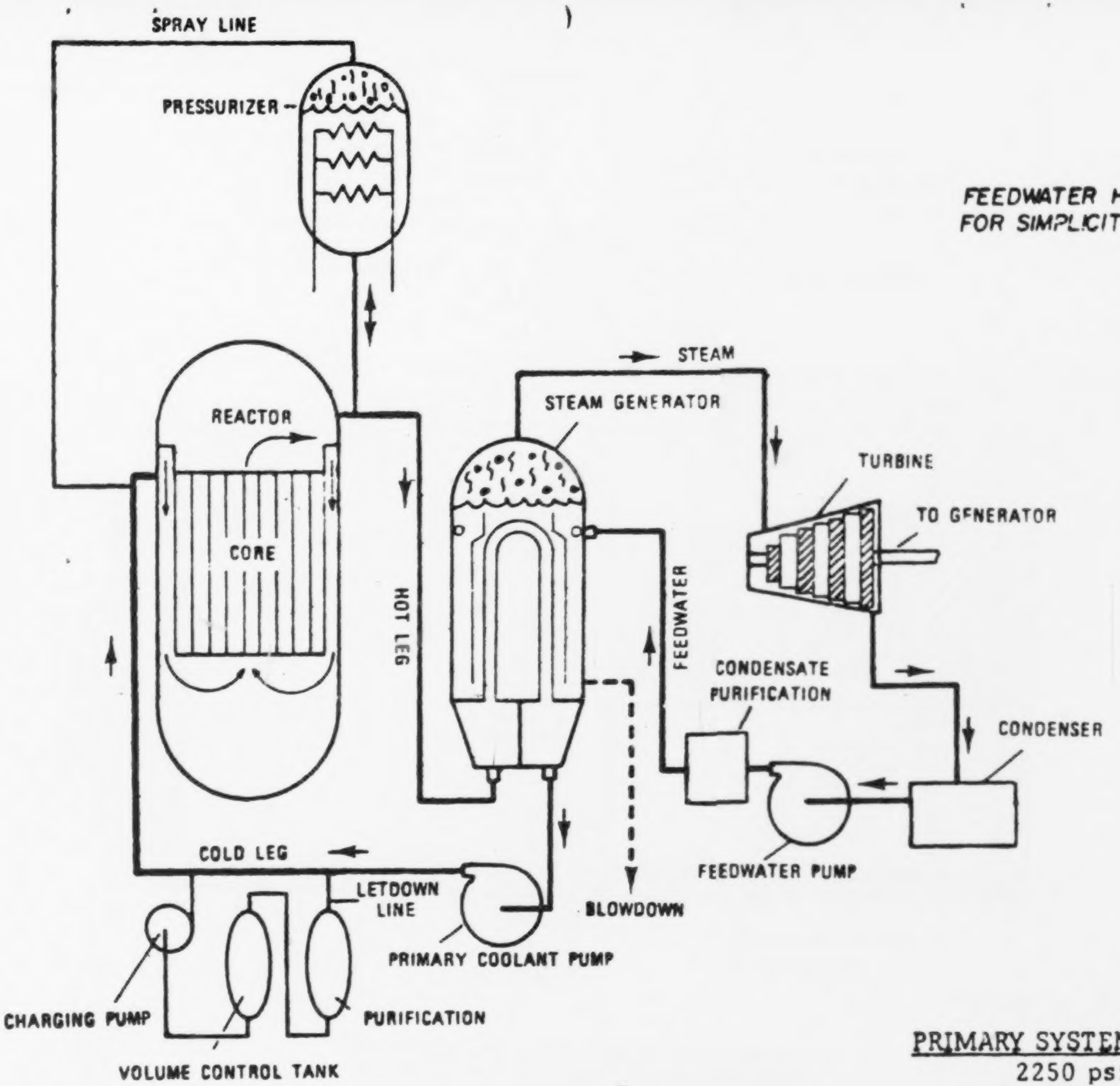
PRIMARY SYSTEM CONDITIONS:
1000 psia
545°F

THROTTLE STEAM CONDITIONS:
965 psia
(540°F)

FEEDWATER HEATERS OMITTED
FOR SIMPLICITY

FIGURE 8

BOILING WATER REACTOR FLOW SYSTEM


SPRAY LINE
PRESSURIZER
REACTOR
CORE
HOT LEG
COLD LEG
STEAM
STEAM GENERATOR
TURBINE
TO GENERATOR
FEEDWATER
CONDENSATE PURIFICATION
CONDENSER
FEEDWATER PUMP
BLOWDOWN
LETDOWN LINE
PRIMARY COOLANT PUMP
CHARGING PUMP
PURIFICATION
VOLUME CONTROL TANK

FEEDWATER HEATERS OMITTED FOR SIMPLICITY

FIGURE ~~2-1~~ 7

PRESSURIZED WATER REACTOR FLOW SYSTEM

PRIMARY SYSTEM CONDITIONS:
2250 psia
605°F

THROTTLE STEAM CONDITIONS:
~800 psia
(518°F)

SCHEMATIC OF A REACTOR COMPARTMENT SHIELD
(SHOWING COMPONENTS AND TERMINOLOGY OF SHIELDING)

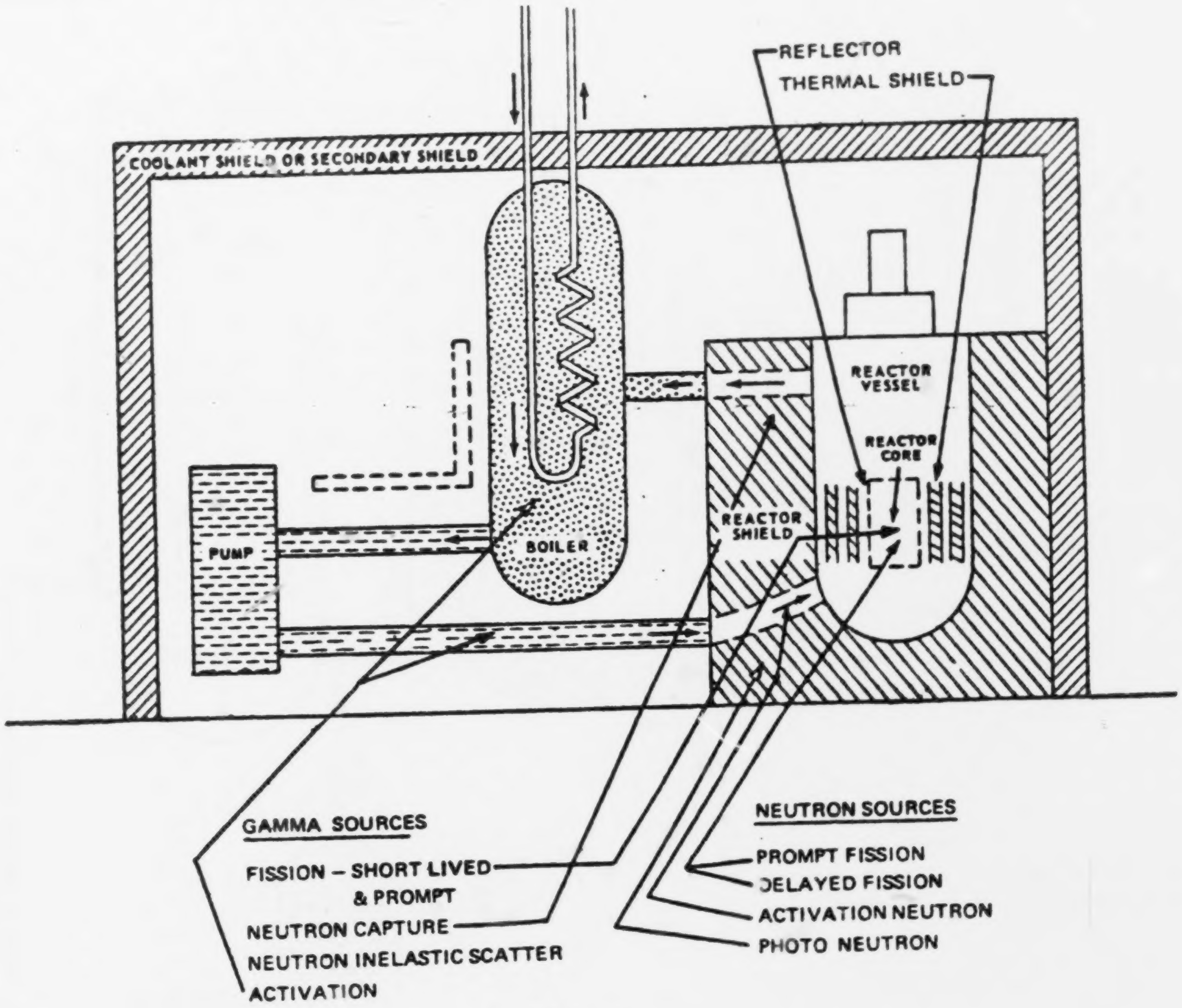
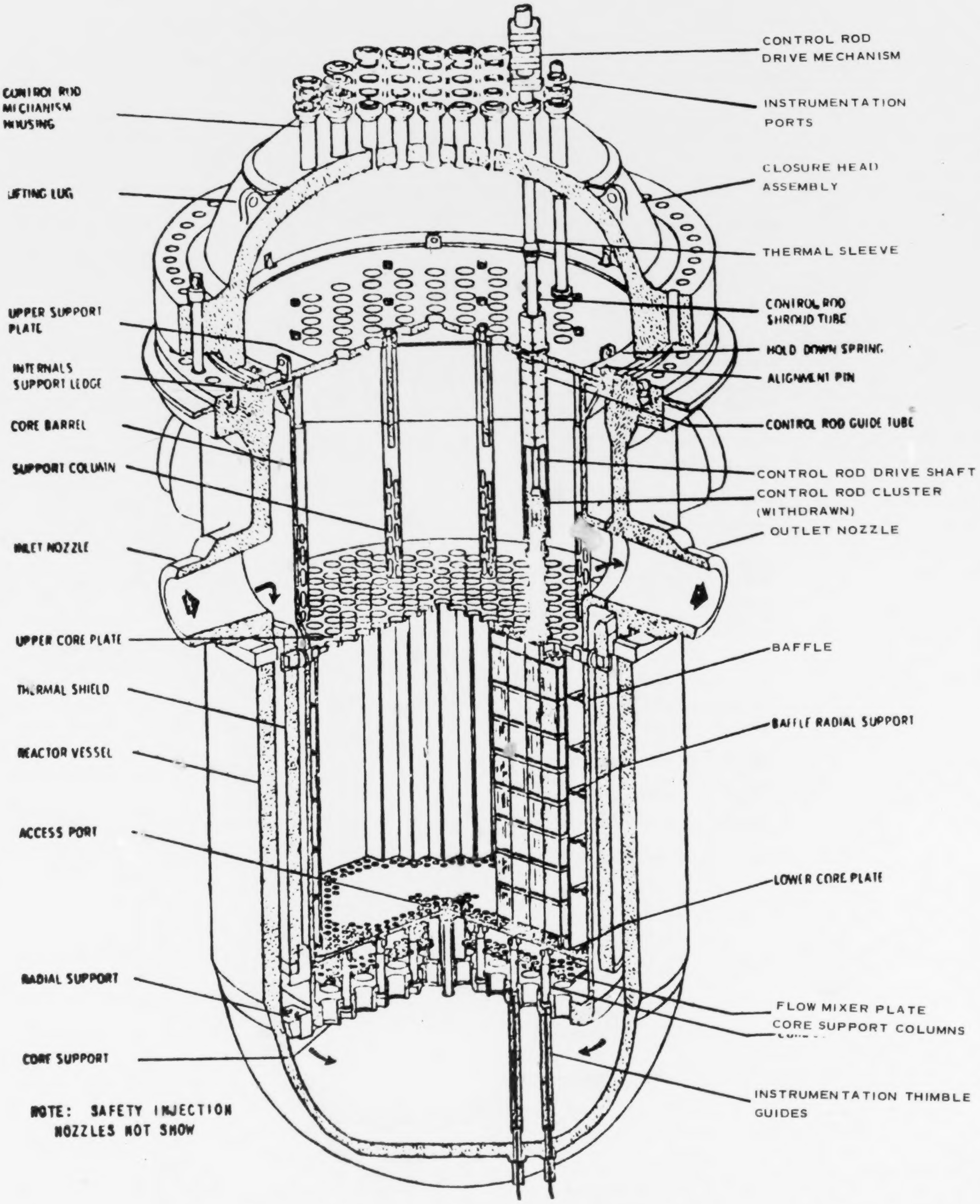

REFLECTOR
THERMAL SHIELD
COOLANT SHIELD OR SECONDARY SHIELD
REACTOR VESSEL
REACTOR CORE
REACTOR SHIELD
BOILER
PUMP
GAMMA SOURCES
FISSION – SHORT LIVED & PROMPT
NEUTRON CAPTURE
NEUTRON INELASTIC SCATTER
ACTIVATION
NEUTRON SOURCES
PROMPT FISSION
DELAYED FISSION
ACTIVATION NEUTRON
PHOTO NEUTRON

FIGURE 10


CONTROL ROD DRIVE MECHANISM
CONTROL ROD MECHANISM HOUSING
INSTRUMENTATION PORTS
CLOSURE HEAD ASSEMBLY
LIFTING LUG
THERMAL SLEEVE
CONTROL ROD SHROUD TUBE
UPPER SUPPORT PLATE
HOLD DOWN SPRING
INTERNALS SUPPORT LEDGE
ALIGNMENT PIN
CORE BARREL
CONTROL ROD GUIDE TUBE
SUPPORT COLUMN
CONTROL ROD DRIVE SHAFT
CONTROL ROD CLUSTER (WITHDRAWN)
OUTLET NOZZLE
INLET NOZZLE
UPPER CORE PLATE
BAFFLE
THERMAL SHIELD
BAFFLE RADIAL SUPPORT
REACTOR VESSEL
ACCESS PORT
LOWER CORE PLATE
RADIAL SUPPORT
FLOW MIXER PLATE
CORE SUPPORT COLUMNS
CORE SUPPORT
INSTRUMENTATION THIMBLE GUIDES

NOTE: SAFETY INJECTION NOZZLES NOT SHOW

FIGURE ~~2-0~~ 11

PWR REACTOR VESSEL AND INTERNALS

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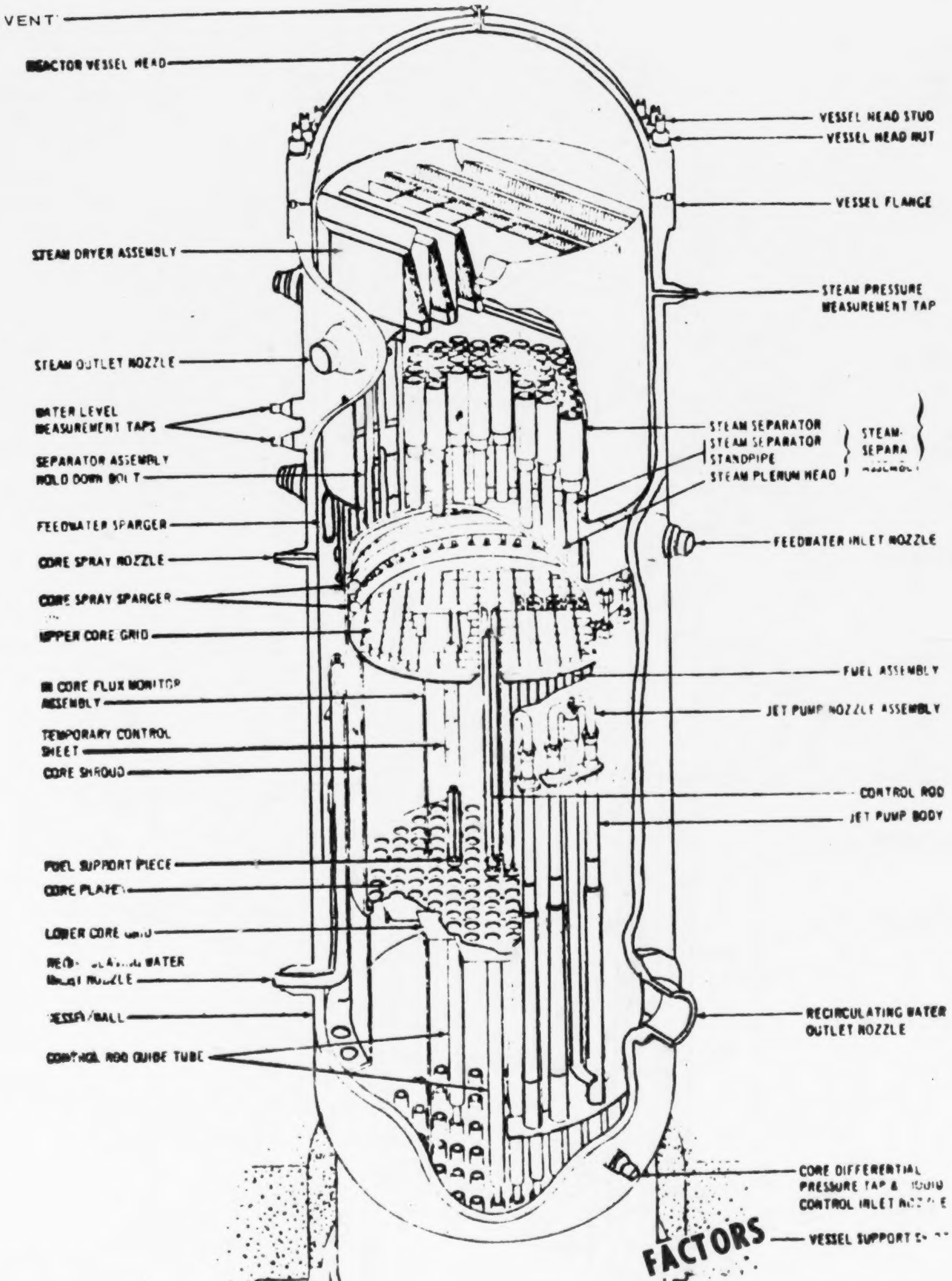
VENT
REACTOR VESSEL HEAD
VESSEL HEAD STUD
VESSEL HEAD NUT
VESSEL FLANGE
STEAM DRYER ASSEMBLY
STEAM PRESSURE MEASUREMENT TAP
STEAM OUTLET NOZZLE
WATER LEVEL MEASUREMENT TAPS
STEAM SEPARATOR
STEAM SEPARATOR STANDPIPE
STEAM PLENUM HEAD
STEAM SEPARA
SEPARATOR ASSEMBLY HOLD DOWN BOLT
FEEDWATER SPARGER
FEEDWATER INLET NOZZLE
CORE SPRAY NOZZLE
CORE SPRAY SPARGER
UPPER CORE GRID
FUEL ASSEMBLY
IN CORE FLUX MONITOR ASSEMBLY
JET PUMP NOZZLE ASSEMBLY
TEMPORARY CONTROL SHEET
CORE SHROUD
CONTROL ROD
JET PUMP BODY
FUEL SUPPORT PIECE
CORE PLATE
LOWER CORE GRID
RECIRCULATING WATER INLET NOZZLE
VESSEL WALL
RECIRCULATING WATER OUTLET NOZZLE
CONTROL ROD GUIDE TUBE
CORE DIFFERENTIAL PRESSURE TAP & LIQUID CONTROL INLET NOZZLE
FACTORS
VESSEL SUPPORT SK
IN CORE MONITOR HOUSING
CONTROL ROD DRIVE HOUSING

TYPICAL BWR REACTOR VESSEL AND INTERNALS

High Temperature Gas Cooled Reactors (HTGR).

In the gas cooled reactor, as the name suggests, the core is cooled by passing certain gases over it. Usually purified carbon dioxide or helium is the gas employed as the coolant. This type of reactor has a low fuel consumption rate, but has several drawbacks. Since gases are not as efficient heat transfer agents as are liquids, a large volume of gas must be circulated. The circulation system requires very large blowers and the core must also be large in order to present enough surface area for effective cooling. Gases also are poor moderating materials, so a separate moderator system must be installed. This moderating system usually consists of graphite blocks placed between the fuel rods. Graphite is used because it is very strong when hot, which permits the reactor to operate at a high temperature. Neither helium nor carbon dioxide will react with the graphite.

Breeder Reactors

Reactors use the fissioning of Uranium-233, Uranium-235, or Plutonium-239 to produce energy in the form of heat. This heat energy is then converted into electrical energy.

Current estimates are that the world's supply of readily available uranium fuel will be exhausted in about 50 years. Breeder reactors are looked upon as a method of extending this limited fuel supply so that it will last far beyond this 50 year span.

Breeder reactors, as the name implies, are reactors which produce more fissionable material than they consume. They do this by the capture of free neutrons produced during the fission process by nuclei of Uranium-238 or Thorium-232. The thorium isotope formed decays into Uranium-233, while the Uranium isotope eventually decays into Plutonium-239. Both the Uranium-233 and Plutonium-239 are fissionable fuels and may be recovered for use in other reactors.

Fuel produced in breeder reactors may extend our supply of Uranium and Plutonium fuels by as much as 50 per cent. However, this process cannot go on indefinitely because the supply of natural uranium to be converted in the breeder is of a limited amount.

One other favorable aspect of breeder reactors is that they can use lower grade ores. We must turn to these ores toward the end of the century because the high grade ores will be largely consumed.

Development of Breeder Reactors

> *"Our best hope today for meeting the nation's demand for economical clean energy lies with the fast breeder reactor. Because of its highly efficient use of nuclear fuel, the breeder reactor could extend the life of our natural uranium supply from decades to centuries, with far less impact on the environment than the power plants which are operating today."*
>
> *Richard M. Nixon*
> *June 4, 1970*

In President Nixon's message to Congress quoted above he established as a national goal the successful demonstration of a breeder technology by 1980. To date the Federal Government has spent some $650 million to develop the liquid metal fast breeder reactor. More will undoubtedly have to be spent. On the other hand, several groups including the Scientist's Institute for Public Information and Friends of the Earth have seriously questioned the government's committment to breeder technology on the grounds of public safety, the need for breeders, and the possible selection of alternative sources of electrical energy.

Just as there were initially many thermal reactor concepts with only the PWR and the BWR winning general acceptance in this country, there have been a number of breeder reactor concepts proposed. The concepts which have undergone initial development include The Light Water Breeder Reactor (LWBR) and The Molten Salt Breeder Reactor (MSBR) which are based primarily on the Thorium-232

-Uranium-233 fuel system and the Gas Cooled Fast Breeder Reactor (GCFBR) and the Liquid Metal Cooled Fast Breeder Reactor (LMFBR) based primarily on the Uranium-238-Plutonium-239 fuel system. Of these the LMFBR concept is receiving the major focus of the research and development efforts in this country and abroad. Thus only this concept will be treated further.

Liquid Metal Cooled Fast Breeder Reactors

Such a reactor would be a breeder since it would be able to produce more fuel (Plutonium-239) from the fertile Uranium-238 than it would consume. In comparison conventional reactors convert only about one atom of Uranium-238 to Plutonium-239 for each two atoms of Uranium-233 or Plutonium-238 consumed.

It is called a fast reactor because it contains no moderator material to cause a rapid slow down of the fission neutrons. Thus the average neutron velocity in the core will be considerably greater than those in conventional thermal reactor cores. At these higher energies there is a much greater probability that the neutrons not needed to maintain the chain reaction will be captured by the fertile Uranium-238 than by reactor core components such as the coolant, cladding and structural materials. It is primarily such capturing of low energy neutrons that keeps conventional reactors from being breeders.

The term liquid metal means that liquid sodium is used as the reactor coolant.

The fuel in such a system would be a mixture of oxides of Uranium and Plutonium.

Liquid Metal Fast Breeder Reactors Compared to Light Water Reactors

Advantages

1. Sodium is considerably more efficient in removing heat from reactor than water.

2. The reactor core can be operated at a higher temperature without pressurization since sodium has a much higher boiling point than water.
3. As a consequence of item No. 2 the thermal efficiency of such a power plant will be 39 per cent or more, compared to 31 to 33 per cent efficiency for light water reactors, thereby reducing thermal pollution.
4. Because of its breeding characteristics the LMFBR would utilize more than 50 per cent of the available energy in the worlds' fissionable and fertile fuel reserves as compared to only one or two per cent for light water reactors.
5. The LMFBR should be able to profitably utilize lower grade uranium ores than the light water reactors thereby increasing the amount of fuel reserves. This results from the fact that because of breeding the fuel cost will be a smaller fraction of the total electrical generating cost.
6. The radiation release problem at the reactor power plant should be reduced since many of the fission products which may leak out of the fuel elements become trapped in the liquid sodium. This is not the case for light water reactors:

Disadvantages

1. Sodium is a very reactive metal which will burn if exposed to either water or air.
2. Sodium is a solid at room temperature and requires an elaborate heating system to assure that it will remain liquid at all times throughout the coolant system.
3. The sodium coolant will capture some of the reactor neutrons and

become intensly radioactive. Since the main radioisotope produced (Sodium-24) has a 15 hour half-life and emits extremely penetrating gamma rays, refueling of the reactor and maintenance of the primary coolant system will require remote control equipment.

4. Sodium is not transparent. This complicates refueling and maintenance.
5. The LMFBR is more difficult to control than a light water reactor because an accidental loss of the sodium coolant from the core results in an increase in reactor power. The opposite effect occurs in light water reactors.
6. The cost of building a LMFBR will be considerably greater than that of light water reactors primarily because of the above mentioned disadvantages.

These problems are now being solved in small operating prototype systems. It is the U. S. goal to develop several prototypes (300 to 500 Mwe) in the 1970's and to have larger (1,000 Mwe) plants operational in the 1980's.

Some other nations appear to be more advanced in the development of breeder reactors than the United States.

Backup Safety Systems in Nuclear Reactors

The nuclear industry is vitally concerned with safety. This safety is a prime consideration when designing and constructing a reactor. There is always a risk that a series of events might result in the failure of safety devices, so these risks are taken into consideration and backup safety systems are incorporated into reactor design. Reviews of these safety designs for all

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proposed reactors are conducted by federal, state, and utility representatives.

All power reactors are designed and built using the *multiple barrier concept*. This concept recognizes that the radioactive fission products must be contained within the reactor system in order to avoid exposing the public to radiation. The fuel used in light water reactors is the ceramic form of uranium dioxide, which has the property of keeping most fission products within the pellet, even when overheated. These pellets are kept within the fuel rod cladding, within the primary reactor system, within the primary containment, which in some designs is within the secondary containment, thus forming a multiple barrier to the escape of the radioactive materials.

Today's water moderated power reactors use uranium dioxide fuel which is enriched with the Uranium-235 isotope only three or four times its natural level. If the rate of fissions were to increase significantly more heat would be produced. This additional heat in turn would increase the energy of the neutrons in the fuel in such a manner that the number of new fissions would be reduced, thus automatically stopping the increase in fission events. This is one reason why a nuclear reactor can in no way become a bomb.

The use of water as a coolant and moderator provides another safety feature of today's power reactors. If the reactor were to *run away* it would raise the temperature of the water, which in turn would decrease the water's ability to moderate neutrons. This would reduce the rate of the reaction, and prevent the possibility of a nuclear explosion.

All the above are used to reduce accident *"possibilities."*

Applied Design Safety Features

Applied design safety features are used to limit accident *"probabilities."*

These include the following:

1. Monitoring of Reactor Neutron Intensity

   Measurements of the number of available neutrons are made by a number of independent monitoring systems at various locations in the reactor core. These instruments are connected to a rapid shutdown system in case the number of neutrons rises above a preselected limit.

2. Reactor Control Systems

   Materials such as boron or cadmium have the ability to absorb neutrons, and so may be used to shut down a reactor by removing neutrons from the system, thus preventing new fissions from occurring. Common methods of introduction include the mechanical insertion of control rods into the core, or the addition of liquid solutions to the water moderator. Most water reactors have both methods of control available.

3. Reactor Safety Circuit Instrumentation

   Instruments constantly monitor what is happening in the core. Improper signals concerning temperature, pressure, or other measurements will cause immediate reactor shutdown.

4. Electric Power Requirements

   Reactor designers assume that at sometime all electric power available to a nuclear plant will be shut off. To allow for this possibility reactor systems are usually designed so that they require no electric power to achieve safe reactor shutdown. Those which may require power are equipped with an emergency diesel generator to supply electricity for the reactor when no outside power is available. These are test run at intervals to insure reliability if and when they are needed.

Engineered Safeguards

Safety features are built in features of nuclear reactors. These features consist of an emergency core cooling network, the on-site diesel generators discussed previously, and the plant containment systems.

1. Emergency Core Cooling Network

   If for some reason there is a rapid loss of coolant water in a nuclear reactor, a danger will exist that the core might melt due to decaying fission fragments, releasing a dangerous amount of radioactive material. Two independent emergency core cooling systems are made available to provide emergency core cooling. The on-site diesel generators are to provide the power to run this emergency core cooling network. The network is fully automatic, and does not require operator intervention during the initiation of the emergency core cooling systems.

2. Containment Systems

   If any of the fission products could find their way through all the barriers and into the air space outside the reactor vessel, the plant containment systems are constructed to keep them confined. The reactor building forms a secondary containment system, and may be sealed off as a further safety move.

CHAPTER 3

BIOLOGICAL EFFECTS: A COMPARISON

In this section we will consider the biological effects of radiation, as well as the gross effects of exposure to the more traditional pollutants: sulfur dioxide, particulates, nitrogen oxides, and hydrocarbons. The greater part of the material will describe the effects of exposure to radiation. The reason is two-fold: *more is known about the effects of radiation on man than is known about the effects of the other pollutants; and radiation effects are less understood by the average person.* Although comparable biological effects may be produced by other pollutants, radiation effects are held by most people to be unique, and somehow more deadly.

It is the intention of this Section to outline for the student the biological effects known to be produced by radiation exposure. Of necessity, these effects will include some of the more spectacular effects of radiation, since the effects are noted only after the individual has received doses well above those encountered in one's day-to-day experiences.

Information on the biological effects of air pollutants from fossil fuel generation appears to be sparse. Difficulties have been encountered in the simulation of an air pollution environment in the laboratory.

In the case of both radiation and traditional air pollutants, most of the reliable data on effects on humans was gained from statistical analysis of large doses.

It has been noticed, in the course of human doings, that "*something*" is described as bad, only after man has noticed that "*something*" exists, or after man is exposed to too much of the "*something*".

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In the case of the air pollutants from fossil fuel generation, it is only within the last 20 years that man has begun to suspect that he might have a problem, and has begun to try to control that problem. This is after centuries of burning fuels for the release of heat energy.

The case of exposure to radiation is similar only in part. Mankind has been living with low levels of radiation since the beginning of his time on earth. He was unaware of its existence until about 1895 when radioactivity was discovered. Until that time his only exposure was to background radiation. He seemed to get along with this radiation background. The early experiments with x-rays soon produced a number of injuries in the experimenters. Almost immediately the use of this new phenomenon began to be controlled.

By the time power reactors began to be built in the mid-1950's, the radiation emitted from these plants was under strict regulation. This is in contrast to the case for fossil fuels, where regulations followed long after plants were in operation.

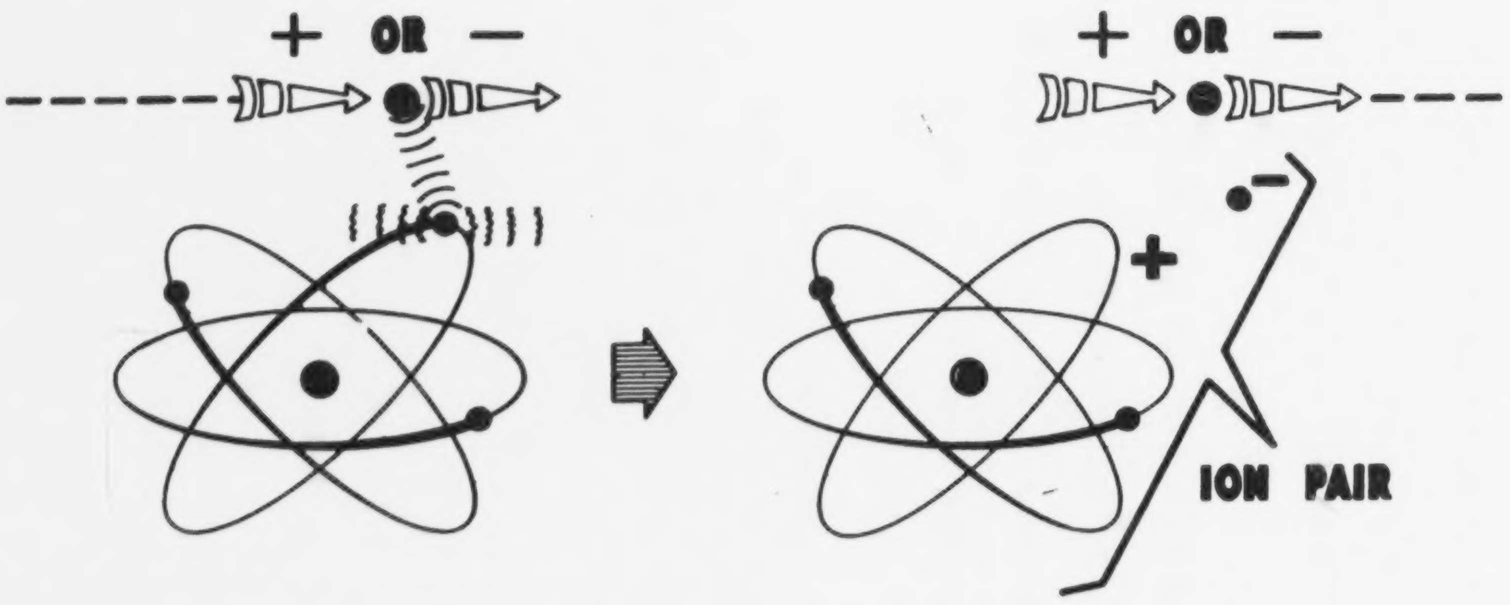
Units

Fundamental Information

All matter is made up of simple units called atoms. These atoms each have a nucleus which has an electrically positive (+) charge. A cloud of electrically negative (-) electrons orbit around the positive nucleus. Ordinarily the number of negative electrons equals the size of the positive charge on the nucleus. The atom is then electrically neutral.

When an electron is separated from the atom, the atom is said to be *ionized.* The atom has a net positive charge since it's missing an electron. This positive atom taken with its separated negative electron is called an *ion pair.* (See Diagram)

IONIZATION BY CHARGED PARTICLE



ELECTRON IS GIVEN SUFFICIENT ENERGY TO EJECT IT

IONS THEN: —REACT CHEMICALLY WITH MATTER
—MOVE IN ELECTRIC FIELDS
—RECOMBINE — EMITTING LIGHT
—SERVE AS CONDENSATION NUCLEI

USAEC-ID-191A

Fig. 13

In some atoms, although they are electrically neutral, the nucleus is not physically stable. The atom becomes stable again by giving off radiation - that is, high energy charged particles or x and gamma rays out of the nucleus. The atom is throwing away excess nuclear material or excess energy. This unloading is called radioactive decay.

There are two kinds of high energy charged particles given off as radiation. They are called alpha particles and beta particles. The pure energy expelled from an unstable nucleus is called a gamma ray. The table below will show you the comparison among these kinds of radiations.

Table I

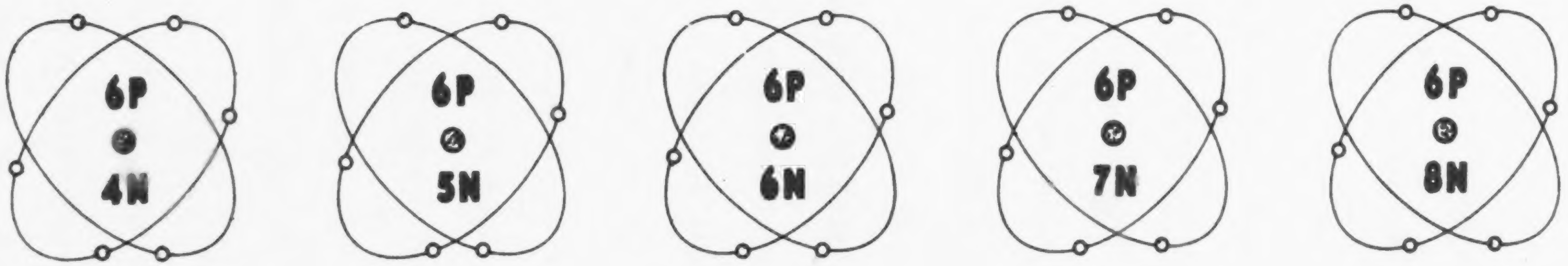
Composition

	Radiation	Protons	Neutrons	Electrons	# Charge
Particulate	Alpha ( )	2	2	0	+2
	Beta (B-)	0	0	1	-1
	Neutron (n)	0	1	0	0
Non-particulate also	Gamma ( ) X-rays	0	0	0	0

When these radiations enter matter, they meet the electron clouds of the atoms. In this process the radiations lose their energy by producing ion pairs.

WHAT ARE ISOTOPES

ISOTOPES ARE ATOMS OF AN ELEMENT DISTINGUISHABLE BY THEIR WEIGHT



CARBON 10	CARBON 11	CARBON 12	CARBON 13	CARBON 14
MAN-MADE	MAN-MADE	OCCURS IN NATURE	OCCURS IN NATURE	[illegible] ~~MAN-MADE~~
RADIOACTIVE	RADIOACTIVE	STABLE	STABLE	RADIOACTIVE

USAEC-ID45A

FIGURE 14

This basic process is essentially the same for *all* kinds of materials - air, water, people, cement blocks, and steel.

Types of Radiation

As seen previously, several types of radiations are emitted in the course of radioactive decay.

The most penetrating of these radiations are x and gamma rays. These rays can completely penetrate a person or a concrete block or a sheet of lead if the ray has enough energy.

Beta radiations which are high energy electrons are capable of penetrating a piece of aluminum foil or several layers of a persons' skin. In air their range may be as much as a yard.

Alpha radiations which are high energy helium ions can sometimes penetrate a piece of paper, but cannot penetrate aluminum foil. Alpha radiations are not important in terms of external radiation. They are, however, the most hazardous of all types from an internal standpoint.

The injury producing potential of any kind of radiation depends on the rate of energy loss as the radiation travels through matter.

The rate of energy loss depends on the electrical charge and energy of the radiation. This energy loss produces ion pairs in the absorbing material. The ion pairs do the damage.

The Roentgen (R)

The first unit, the Roentgen, is the special unit of exposure defined as a number of ion pairs produced in air. This unit applies only to x and gamma radiations. It is a unit describing effects in air produced by radiations (x and gamma rays). It can be measured directly since it produces an electric current which can be measured with an ammeter.

Radiation Absorbed Dose (RAD)

The next unit is the RAD. It is the special unit of absorbed dose. It measures the amount of energy left in material by the radiation - any kind (alpha, beta, gamma). It does not only measure ion pairs but all energy deposited. A RAD is very small. For example, one RAD is equal to the energy required to raise your body temperature only 2 one-millionths of one degree Farenheit.

Roentgen Equivalent Man (REM)

The third unit, the unit of dose equivalent, is the REM. It not only measures all energy deposited but also the biological effects resulting.

For instance, 500 rads of gamma rays may produce a certain change in a tissue. Fifty rads of alpha particle radiation do the same. Therefore we say that the alpha radiation was ten times as powerful in causing this change - or it would have a *quality factor* of 10 as compared to the gamma ray. The REM equals RADS x Quality Factor.

In this example the quality factor for gamma radiation is 1. Therefore 500 RADS x 1 quality factor = 500 REM. The alpha quality factor is 10. Therefore, 50 RADS x 10 quality factor = 500 REM. The effects are the same, the REMS are equal.

Since radiation protection deals with the protection of people from unnecessary radiation exposure, regulations and recommendations are written in terms of the REM. Maximum permissible exposure allowed for a radiation worker in one year is 5 REMS.

Summary

To review, then, a roentgen refers to the ions produced in air by x and gamma radiation. A rad refers to the energy deposited in any material by any ionizing radiation. A rem refers to the results of that energy deposited in tissue.

Moderating Influences

Since some radiation effects are observed after relatively small doses while others require much larger doses, it is apparent that other factors than the energy moderate the final reaction produced.

Dose Rate Effects

Knowledge of effects of radiation has generally resulted from experiments using large doses of radiation in a short time. For example, if 100 rems were delivered to a person in one hour, that rate is greater than if 100 rems were delivered in ten years. One hundred rems in one hour is a high dose rate.

Most human exposure is low dose and low dose rate. To see the biological effects of this type of exposure one would have to observe very large groups for very long periods - generations. Therefore, it has been the general practice to predict the results of this low dose from the data from high dose experiments. It is assumed that some injury results from any exposure to radiation. It is assumed that a *threshold* dose does not exist.

Living tissues are not inert. As soon as damage is produced, healing (repair process) will begin. If a particular dose is delivered over a long period of time, it is possible that repair may keep up with damage. No visible change would be produced. On the other hand, if that same dose is delivered all at once, a noticeable reaction may be provoked.

The effectiveness of low dose rate in reducing radiation damage depends in part on the cell (or tissue) and in part on the effect being studied. For example, the irradiation of a person during a critical period of cell division in a given organ could increase rather than decrease the effect.

MAXIMUM PERMISSIBLE TISSUE DOSE
REMS PER WEEK

TYPE OF RADIATION	AT ANY POINT WITHIN BODY	Factor* ~~RBE~~	IN THE BASAL LAYER OF THE EPIDERMIS: EXPOSURE OF ENTIRE BODY	IN THE BASAL LAYER OF THE EPIDERMIS: EXPOSURE OF HANDS ONLY
X-RAYS & GAMMA RAYS	0.3	1	0.5	1.5
BETA RAYS	0.3	1	0.5	1.5
PROTONS	0.03	10	0.05	0.15
ALPHA RAYS	0.015	10 – 20	0.025	0.075
FAST NEUTRONS	0.03	10	0.05	0.15
THERMAL NEUTRONS	0.06	5	0.1	0.3

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FIGURE 15

Age and Sensitivity

The age of the exposed individual can greatly affect his sensitivity to radiation. At certain stages (when organs develop before birth) the sensitivity is high, because differentiating cells and cells undergoing rapid division are more easily damaged. Similarly, in the period between birth and maturity, high rates of cell division with possible further differentiation make the individual more sensitive to radiation exposure.

The adult is more resistant to radiation than juveniles. His exposure, however, may give rise to genetic effects in his children. In a person beyond the reproductive age, the genetic effects are not important. Similarly, for old persons (with a decreased life expectancy) radiation effects that appear only after a long time (i.e. tumor induction) are not as significant as with younger people.

Part of Body Irradiated

If the upper abdomen or possibly the backbone are irradiated, general reactions are much more severe than if a body area of similar size elsewhere were exposed to the same dose.

Extent of Body Irradiated

Irradiation of a small part of the body surface will have much less general effect than an equal dose per unit area delivered to the whole body. On the other hand the effect on the smaller area can be severe. It can produce some degree of permanent local change even when general (systemic) effects do not result.

Remember that we have been thinking in terms of radiation from something outside the body (external dose). When radioactive materials are taken into the body, general distribution (whole body effects) may occur. When radioactive material is taken into the body through food, water, air, medicine, etc., it moves through the body in the same manner as the non-radioactive material. The body cannot tell the difference between the radioactive material and its non-radioactive relative. The radioactive material is removed from the body in the same biological manner as the non-radioactive form, and by radioactive decay.

With external radiation, the dose to the individual can be reduced with shielding, distance, or short exposure time. With internal radioactivity, the reduction of dose is not so simple. Also with internal radioactivity, the amount of material required to bring about an effect is much smaller than that required from an external source. This is because the material becomes a part of the living tissue. The harmful effects of the material depend on:

1) The sensitivity to radiation of the organ or tissue to which the material goes - the critical organ.
2) The type of radiation emitted, its quality factor.
3) The time it takes the body to remove one-half of the radioactive material - the biological half-life.(T_B)
4) The physical half-life of the material. The T_p and the T_B combine to decrease the radioactive concentration. Together they tell us the effective half-life (T_E) of a radioactive material - the time that it takes a person to reduce the amount of radioactive material to ½ of the original amount.

$$\frac{1}{T_E} = \frac{1}{T_p} + \frac{1}{T_B}$$

5) The physical and chemical form of the material.

You can see that a long lived radionuclide (long T_p) that emits alpha particle and is deposited (with a long T_B) in bone is harmful. It is more harmful than an equivalent amount of radioactive material that gives off a high energy gamma ray, is not easily absorbed into the body (short T_B), and does not concentrate in any organ.

Biological Variation

It is possible to determine an average dose which produces certain effects. In a large population, some individual responses will vary from those of the average. For instance, it required 600 rads in a single dose to kill half of a group of rats within 30 days. On the other hand, some of these rats died after 400 rads and some lived after 800 rads. This is biological variation.

Effects

Types of Biological Effects

Biological effects of radiation are divided into two general classes: somatic effects and genetic effects.

Somatic effects are those observed only in the person who has been irradiated.

Genetic effects are those effects seen only in the offspring of the person who has been irradiated.

Exposure to radiation can produce both kinds of effects.

Somatic Effects

Somatic effects refer to body damage rather than genetic damage.

When a small dose of radiation energy is deposited in a person it may have no visible effect. With somewhat larger doses harmful effects are seen, but complete recovery may result. With still larger doses all of these harmful effects are increased in severity and complete recovery is impossible. With even larger doses death results.

The first event in the absorption of ionizing radiation is the production of ion pairs. When these are produced in chemical systems of a cell, new and possibly harmful chemicals are produced as the original chemicals are broken up by the radiations. As a result, toxic materials may be produced.

If the radiation affects chromosomal material within the cell nucleus, cell division may be affected. An observable change may or may not take place in an individual cell following irradiation. The individual organism may or may not feel or observe the results of that irradiation.

At the cellular level, the response to radiation seems to be determined by a number of factors:

1) Stage of specialization of the individual cell,

2) Activity of the cell, and

3) Division rate.

This would account for the sensitivity to radiation of rapidly dividing cells in a tumor or in an embryo. In the embryo a small group of cells eventually will specialize or form an organ. This accounts partially for the greater sensitivity of the embryo compared to that of the adult.

In summary then, the cell may respond to irradiation by chromosomal changes, cell death before division, failure to specialize, failure to divide completely or a slowing of division rate. However, some cells will be unaffected.

Organ Sensitivity

The radiosensitivity of organs and tissues depends on cell multiplication. In the lining of the gastrointestinal tract, some of the cells are mature. These are continuously discarded. These cells are continuously replaced by new ones produced nearby. It is the dividing parent cells that are injured.

The rapidly dividing cells are severely decreased in number at high dose rates of radiation. If the dose is not too high, the cells still living will begin to replace those destroyed.

If a large dose is given to a small area of the body, the general and local effects will depend on what organ was irradiated. For instance, a large dose to an arm will not result in death or severe damage to the blood making system. This is because the majority of the blood making system is not in the arm and was not exposed. An unirradiated supply of these cells exists elsewhere (ribs, spine, etc.). There will very likely be detectable (and severe) changes in the arm.

Total Body Doses

Most of the information on the effects of radiation in man were gathered from occupational, medical and atomic bomb exposure (the Hiroshima survivors, victims of radiation accidents, patients receiving radiation therapy). These were generally high dose rate events.

Another source of observation includes animal experiments. These may or may not be relatable to man.

Most of the currently available information was calculated from the observation of effects at levels of radiation much higher than those to which the public and the radiation worker are regularly exposed.

The effects of large sudden doses of radiation are called the *"radiation sickness syndrome"*. Radiation sickness consists of nausea, vomiting, general aches and pains possibly accompanied by changes in the blood (decreased white cell count). Localized phenomena (red skin or hair dropping out) may be produced.

Larger doses cause weakness, drastic changes in the blood (depression of all the elements - red, white cells, platelets, hemoglobin). Sterility may result. Exposure of the eyes may produce cataracts (blindness due to clouding of the lens of the eye). At still higher dose levels death may occur. The effects of long term, low dose rate chronic exposure can only be predicted. Similar effects also may occur spontaneously in the population as the result of exposure to other environmental agents. This complicates the evaluation of the effects of these doses. Another problem which makes this difficult to assess is the fact that these low dose effects generally develop only after a long time following exposure.

Cancer and leukemia are a long-delayed consequence of a single large exposure. They may also follow chronic exposure. It is by no means an inevitable result of any form of human exposure.

Of the abnormal growths that might result from radiation, leukemia is one of the most important. It accounts for about 1/6 of all new growths (cancerous and non-cancerous) seen after high doses of radiation. These are seen most frequently some 10 years or more after exposure to 100 rads or more. Lower doses from diagnostic x-rays on an expectant mother have been associated with childhood leukemia and other tumors. The limited and inconclusive evidence so far shows that a whole-body dose of a few rads at one time may increase the leukemia rate in exposed children from 0 to 50 per cent above normal occurrence. The central nervous system and skeleton also may be damaged.

Thyroid cancers have increased in children receiving 200 rads or more during x-ray therapy of the head, neck and upper chest.

Much recent special attention is directed at the increased incidence of lung cancer in uranium miners. This may be due to the inhalation and deposit of the decay products of radon, (alpha-emitters) in the lining of the lung.

Cataracts are sometimes observed following high doses. These, in contrast to most radiation induced diseases, are different from cataracts caused by other agents.

Impairment of growth is seen with total body irradiation. This was found in Japanese children exposed to the bomb, and in the Marshall Island children following fallout. Irradiation of growth centers in bone inhibits bone growth.

Japanese children exposed in the first months of embryonic life to doses of 50-100 rad have shown increased incidence of mental retardation and reduced head size.

Life shortening is observed. Some changes occur at the cellular (or higher) level that lead to effects similar to aging process. This has been shown in animals. It is obviously difficult in man to obtain quantitative dose effect data for life-span shortening. It is probable though, that some degree of life shortening from radiation in man may occur following high-dose exposure.

Genetic Effects

The term - *genetic effects* - refers to the production of *mutations* in germ cells. These mutations occur in all living organisms. They may occur of their own accord, apart from any known alteration in the environment. Whatever their origins, most mutations are undesirable. Every individual has some of these undesirable mutations.

Radiation induced mutations are divided into two classes: gene-mutations and chromosomal abnormalities. Most radiation-induced alterations in genetic material can be classified as gene-mutations. These tend to be recessive. In other words, the effect is not seen in the children unless the altered gene is carried by both parents. The mutations, although not really seen in the first generation offspring, make him slightly less fit.

Chromosome loss and chromosome breaks can occur. In this instance the damage to the parental germ material has been more dramatic. The result is generally death of the embryo before birth. This type of genetic effect happens much less frequently than does the gene mutation.

The increase in damage to be expected from radiation is usually discussed in terms of a *"doubling dose"*. This is the dose that would eventually cause a complete doubling in the rate of gene mutations.

In the United States at present approximately 100 million children are born in a generation. Of these about 2 million will have genetic defects as a consequence, of *"spontaneous"* unavoidable genetic changes which have occurred during the lifetime of all their ancestors. If a *"doubling dose"* of radiation were applied to the total population for many generations this would eventually produce 4 million defectives. This, however, would take a very long time.

Summary

In conclusion, then, it appears that the effects of radiation may be observed in the cell, the tissue, the organ and the total individual.

It is assumed that some damage (somatic or genetic) results from any radiation exposure, including background. For a comparison with fossil fuel pollutants, please see page 99.

Repair

The phenomenon of *"repair"* following radiation exposure has been observed. It is a principal used in radiation treatment. For example, a patient having a series of x-ray treatments receives a total dose larger than that required to kill if it were given in a single exposure. When the exposure is divided into a number of exposures instead of one dose, the cells begin to repair the damage. The rapidly dividing cancer cells have a greater chance of being destroyed because their growth rate is greater than that of the normal tissue.

This repair and recovery, however, is not true for all cell types. It does not reduce the genetic damage in some germ cells.

Non-Human Biological Effects

In the earthly environment hundreds of thousands of species of plants and animals have been identified. [illegible] is reasonable to expect that a wide range of sensitivities to radiation would be seen in this great variety. While radiation protection guides are written to protect man, much of the data upon which these guides are based was derived from animal experiments.

The basic conditions that tend to predict radiosensitivity in man, such as cell division rate, age, are applicable to all other life forms as well. However, there is a wide range of variation among species.

A number of types of organisms have been known to reconcentrate radioactive materials in their bodies. An example is the case of shellfish such as oysters and clams. These organisms can reconcentrate certain radionuclides up to 100,000 times the levels found in the water in which they live. This reconcentration does not appear to affect the well-being of the animal. But a person who uses these shellfish as his sole source of food could receive a significant fraction of his maximum permissible dose. For this reason, edible shellfish living near the outfall of a nuclear plant are included in the environmental surveillance program. This reconcentration ability also makes the shellfish a good monitor for cross checking radioactive discharges.

By *"cosmic"* radiations we mean those high energy radiations which have been discharged out by the sun. They then interact with our atmosphere to produce a shower of charged particles. The natural radioactive materials like uranium and thorium are widely distributed in soil and rocks. The more energetic radiations from these radioisotopes serve to irradiate us continuously.

Another source of natural radiation is the building materials of our homes, schools and places of work. The background received by a person living in a wooden house is about 100 mrem per year; a brick and concrete house will range from 150 to 300 mrem/year.

Sources of natural internal contamination include the radioactive isotope of potassium, potassium-40. A small part of all potassium is potassium-40. Similarly part of all carbon is radioactive Carbon-14. Radium, lead and radon are radioactive products of uranium. These materials are present in small quantities in the food we eat and air we breathe.

The amount of radiation dose we get from natural background varies according to the place we live. For example, cosmic radiation dose doubles if you move from sea level to 10,000 feet(if you move from Philadelphia to a town high in the Rocky Mountains). This exposure increases by 15 per cent as you move from the equator to a geomagnetic latitude of 50°.

Similarly, the dose from radiation in rocks varies with location. Moving from one part of New York City to another may give you an additional 15 mrem/year dose.

In addition to these natural sources of radiation dose, there are several sources of artificial radiation dose, which we share

SOURCE	GENETIC DOSE (mrem/year) (average)
Medicine and Dentistry:	
Diagnostic (1964)	55
Therapeutic	12
Internal (radionuclides)	1
Environmental:	
Weapons fallout	4
Reactor-site boundary	5
Reactor-average person in the population	0.01 to 0.1

The average dose-rate from medical X-rays is about 55 mrem/year, while that from the operation of reactors is estimated to be 0.1 mrem/year at the present time.

To put this all into perspective: if you had to make the choice of the best way or group of ways to reduce radiation exposure, what would you decide?

1) Prohibit people from living in brick and concrete houses. Require everyone to live in wooden houses. This would save 50 to 200 mrem/year for each person now occupying that kind of structure.

2) Work to reduce our medical x-ray exposure from the current 55 mrem/year to say, 15 mrem/year as it is in most of Europe. This would save each of us about 40 mrem/year.

3) Prohibit people from living in Manhattan. Require them to move to Queens, at a saving of 15 mrem/year for each person.

4) Require reactors to reduce their radioactive effluents by a factor of ten, saving each of us 0.009 to 0.09 mrem/year.

WHAT WE KNOW ABOUT THE EFFECTS OF LOW LEVEL RADIATION

It should be recognized at the outset that there is no such thing as absolute safety in the field of radiation - or in any other field of human experience. Safety is a relative consideration, and can only be considered within the framework of all the risks with which man is faced. When we use the term "*safe*" we must clearly understand the difference between absolute and relative safety. Perhaps a better term would be "*acceptable*".

There is an extensive body of knowledge about the effects of high level ionizing radiation on man. An important part of this knowledge came from studies on the survivors of Hiroshima and Nagasaki, the Japanese cities upon which atomic bombs were dropped in the closing days of World War II. But this information is of very limited use when attempting to predict the effects of a few thousandths of a rad per year on a large number of people.

To quote Lauriston S. Taylor of the National Council on Radiation Protection and Measurements,

> *"... there is a considerable region of radiation exposure about which we have very little positive knowledge. This is in the region of doses of one or two, or even a few rads, delivered all at once and not repeated too frequently; larger doses, say up to 10 or 20 rads received essentially all at once but rarely, if ever, repeated, and finally exposures at very low levels and at low dose rates, say at millirads or less per day, but persisting over long periods and totalling only some five or ten rads distributed over a lifetime.*
>
> *It is particularly this latter condition which is of concern to the public with the use of nuclear reactors and it is this range and kind of exposure upon which we have little positive and direct knowledge. But it is in this same range of exposure that we have made a tremendous effort of attempting to discover effects, with all results so far being convincingly negative. This inability to find effects is itself extremely important, but it must be recognized that the test samples may not have been large enough. ... the levels of dose about which the public is concerned in the nuclear power industry are at the most a few thousandths of a rad per year, and more likely less than a thousandth.*

> *... the upper dose limit to the population for all man-made radiation is 700 times less than the lowest dose of gamma rays which has been statistically shown to cause leukemia.*
>
> *At the same time the population dose limit is at least some hundred times higher than the average dose to the population from all the reactors expected to be installed between now and the year 2000, assuming no improvement in our protection techniques."*

Perhaps the only problem is that we do not know how to measure the effects of such very low doses of radiation because they are too small or happen too infrequently to be measured. This means that if the effects cannot be measured by any of the fairly sophisticated methods that we have available today, the potential hazard - if it exists at all - is sufficiently small so that there is time during which to further study and analyze the problem without putting a serious number of people at risk.

However, this very fact of being unable to detect any effect, accompanied by an unwillingness to say that there is no effect at all, has led us into a dilemma. In order to avoid setting standards which would expose the public to an unnecessary and what, possibly, in the light of future knowledge may turn out to be, a dangerous amount of radiation, the National Council on Radiation Protection and Measurements has set exposure limits based upon the following very cautious assumptions:

1. There is a single, linear dose-effect relationship for the effects of radiation from zero dose with no effect to the known effects of high level doses.
2. There is no threshold of radiation below which there is no effect. We assume, rightly or wrongly, that all radiation has an effect, and that this effect is harmful.
3. All doses received by an individual are additive - that is, their effects add up.
4. There is no biological recovery from the effects of radiation.

We must keep in mind that we know that all available evidence indicates that several of the above assumptions simply are not true, but in the interest of safety we merely assume that they are, under the conservative philosophy that it is far better to be oversafe than sorry at some future date.

To keep the dosage which we may expect to receive from nuclear power plants in perspective, the maximum permissible dose arrived at as a result of the above mentioned considerations is presently set at 167 millirems per year, the maximum exposure to the public from the combined effect of all nuclear power plants expected to be constructed by the year 2,000 will not be greater than 1/100 of a rem, far below the maximum permissible dose.

Let us compare this dose to the normal public exposure which a person might receive from other sources of radiation. Each person received in excess of 100 millirems per year from normal background. Normal medical and dental X-rays account for an additional exposure to the general public of 55 millirems. An airplane trip across the United States would result in more radiation exposure above normal background than an individual living within a mile of a reactor would receive in almost a year.

BIOLOGICAL EFFECTS OF FOSSIL FUEL GENERATORS

Units

In reviewing the literature on the effects of various air pollutants, the unit most frequently encountered is *"parts per million:"*. This term is an expression of concentration of a gaseous air pollutant such as sulfur dioxide, in another gas, air. One part per million (ppm) means one part of pure reference gas in 1,000,000 parts of air.

Sulfur Dioxide

Sulfur dioxide is the air pollutant that most people talk about. This pollutant is a gas that is produced when fuels containing sulfur are burned. It is a colorless gas which most people can taste at concentrations greater than 0.3 ppm. At concentrations above 3 ppm the gas has an irritating smell. In the environment, SO_2 is transformed to sulfur trioxide or to sulfuric acid and particulate sulfate salts. These conversions depend on the presence of moisture in the air, on the presence of dusts and smokes, and on the intensity and duration of sunlight.

It appears, from the current information, that the health effects of the oxides of sulfur are related to injury to the respiratory system. This system includes the lining of the nose, the throat, and lungs. The injury may be temporary, or it may be permanent.

Laboratory studies show that SO_2 constricts the bronchial tubes of the lungs of experimental animals. When sulfuric acid or particulate sulfate salts are formed, the irritation is greater for the same concentration than for SO_2 alone.

When SO_2 and particulate contamination are present in the air at the same time, the SO_2 conversion to sulfuric acid is encouraged. The injurious effects of the SO_2 can be increased three to four times in the presence of the right kind of particulate matter. In this case 1 plus 1 equals 3 or 4.

In general the laboratory work performed thus far is not entirely relevant to the real environment. In the real environment, the concentrations of a whole spectrum of pollutants are constantly changing. The lev of moisture in the air is changing. The intensity of sunlight varies. The temperature rises and falls. Although it is very difficult to reproduce all these changes in the laboratory, valuable information on the interrelationships of these changes and SO_2 has been gathered. It has shown, for instance, that it is not wise to measure only one pollutant in the air, and then use that data alone to describe the quality of air in that community.

Another way to study the problem is through the use of the science of epidemiology. This science deals with the study of the movement of an injury or disease through a population after the injury or disease begins to be noticed. The epidemiologist must think of all the possible causes for the disease in the group of people, and then carefully eliminate all the causes except one. These epidemiological studies lack the controlled conditions of the laboratory. Their advantage is that they are carried out in the real life environment. From these studies, it has been clearly concluded that the oxides of sulfur in the air have an effect on the health of a group of people, and that the severity of the effect is directly related to the degree of pollution.

The results of some epidemiological studies of the effects of sulfur dioxide are listed below.

LOCATION	SO_2 Concentration (ppm)	EFFECTS
London	0.25	rise in daily death rates after abrupt rise to 0.25 ppm.
London	0.35	distinct rise in deaths with concentration over 0.35 ppm for one day.
London	0.52	death rate appeared to rise 20 per cent over baseline levels.
New York	0.5	excess deaths were detected after 24 hours at concentrations over 0.5 ppm.
Rotterdam	0.19	apparent increase in total mortality after a few days at a mean concentration of 0.19 ppm.
New York	0.007 to 0.86	rise in upper respiratory infections and heart disease complaints during the 10-day period.

London	0.20	this one day average accentuated symptons in persons with chronic respiratory disease.
Chicago	0.25	this one day average increased illness in older patients with severe bronchitis.
England	0.046	this long term level increased frequency and severity of respiratory diseases in children.
England	0.040	this annual mean produced an increase in death from bronchitis and lung cancer, with cigarette smoking, age, occupation and class taken into consideration.

Particulates

The effects of particulate air pollution, or dust, on health are related to injury to the respiratory system. The injury may be temporary, or it may be permanent. The damage may be due tp the particulate itself, or to the gases, like SO_2 which are carried on the dust particles.

Here, again, it is difficult to separate the effects of the particulate from the effects of other known pollutants in the air.

In the previous table of effects of SO_2, in most of the studies cited, the particulate load in the air was proportional to the SO_2 concentration.

Nitrogen Oxides

This class of pollutants includes nitric oxide (NO) and nitrogen dioxide (NO_2). NO is formed during all atmospheric burning processes in a chemical reaction between nitrogen and oxygen in the air NO_2 is formed slowly by a reaction between NO and atmospheric oxygen. Together these nitrogen compounds are termed NO_x. NO_2 is the more hazardous of the two compounds.

Nitrogen dioxide (NO_2) has been significantly correlated with increases in respiratory diseases, at mean daily concentrations between 0.062 and 0.109 ppm, in Chattanooga, Tennessee.

Nitrogen oxides play a significant part in the formation of smog.

In laboratory animals, inhalation of ozone increases the susceptibility of the animals to bacteria. Some animals gradually develop a resistance to ozone. There also is some evidence of an apparent increase in the rate of aging in the animals, similar to the changes produced by exposure to free radicals or by radiation.

A Table of Risks

Risk	Probability of Fatalities per person-hour of exposure
Motor Vehicles	1 in 1,000
General Aviation	1 in 100,000
Smoking	1 in 1,000,000
Hunting	1 in 1,000,000
Commercial Aviation	1 in 1,000,000
Railroad Travel	1 in 100,000,000
Electrocution	1 in 1,000,000,000
Coal Burning Plants	1 in 1,000,000,000
Nuclear Plants	1 in 10,000,000,000

- Chauncey M. Starr.

CHAPTER 4

WASTES IN THE PRODUCTION OF ELECTRIC POWER

Radioactive Wastes in the Production of Nuclear Power

The first point where waste products which contain measurable amounts of radioactivity appear in the nuclear power production cycle is with the mining and milling of the fuel materials.

No new activity is produced at this point. These materials have existed since the beginning of time. The material however, is being brought to the surface of the earth and concentrated. The materials which are removed for use such as uranium and thorium find their way into the fuel elements for reactors, but the radioactive *daughter* products of uranium such as radium and radon which are usually not present in commercially valuable amounts find their way into tailing piles and milling byproducts as well as into streams. What can be done with these low level solid wastes? One unsatisfactory solution to this problem came to light recently when it was discovered that some of these tailings were used in Colorado as land fill for a housing project. The radiation level in the homes was found to be several times above the normal background level, due to the presence of the gaseous element, radon. Needless to say, these homes have now been vacated. The practice of using these tailings for land fill is now forbidden by law in most states.

In addition to the solid wastes from fuel preparation, an average mill processing 1000 tons of Uranium ore per day will discharge 300 to 500 gallons of radioactive liquid wastes per minute. There are over 20 such mills in the United States at the present time. Thus a large amount of these low level liquid wastes are being produced.

The natural fuels as they are produced usually require further processing or enrichment, which also results in more wastes containing natural radioisotopes. For each ton of uranium processed, approximately 1000 gallons of liquid wastes are produced.

The purified uranium used in the fabrication of fuel elements has extremely low activity because the radium, thorium and other radioactive products have been removed in earlier steps in the cycle. Liquid wastes from fuel fabrication plants are of small volume and very low radioactivity. Contaminated scrap is also produced at these plants.

Fission fragments produced by nuclear fuels in reactors are by far the largest source of radioactive waste in terms of contained radioactivity. When each uranium atom fissions or splits, it breaks into two major fragments (elements with smaller nuclei). These fission fragments are radioactive, i.e. they undergo one or more steps of radioactive decay before reaching a stable, harmless condition. Valuable unused fuel remains in the fuel element along with the accumulated fission products. In fact, under proper conditions such as exist in breeder reactors more new fuel may be produced than is used. The recovery of this fuel is necessary for the economic operation of power reactors. Chemical processing of the used fuel elements is, therefore, an important part of the nuclear industry. This processing creates highly radioactive wastes consisting of not only fission products, but also activated materials originating in chemicals, the structural materials of the fuel elements, and corrosion products.

A number of solvent extraction processes are used to separate remaining fuel from waste products in used fuel elements. From 1 to 100 gallons of highly radioactive liquid result from each kilogram of fuel processed.

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The present Atomic Energy Commission policy, revised Nov. 14, 1970, permits some private firms to operate fuel reprocessing facilities subject to federal policy regulation. A brief partial summary of these policies is as follows: plants are not required to be on land controlled by Federal Government, limit of inventory on high level wastes (amount produced in prior five years); all wastes must be converted to solid for shipment in proper type of container; all high level wastes shall be transferred to federal repository no later than 10 years following separation, industry pays all cost of disposal, disposal only on land owned and controlled by Federal Government, plants must be designed to permit decontamination when facility is decommissioned, all plants must be licensed.

Activation Products

Activation products are produced during the irradition of nonfuel materials located near the fuel in nuclear reactors. How do these materials become activated? The process of fission produces large numbers of free neutrons. These neutrons may be captured by the nucleus of nonfuel materials present in the reactor. The nucleus formed by the neutron capture is often unstable and decays, giving off radiation.

Structural materials, impurities in the coolant and sometimes the coolant itself may be activated by this process. In water cooled reactors, radioactive products arise from the irradition of the water as well as from irradiation of any air dissolved in the coolant. The radioisotopes produced are mostly short lived including nitrogen -16 (7.3 sec), oxygen -19 (30 sec) and argon -41 (1.8 hr.). However, also produced are tritium or hydrogen -3 (12.3 years) and carbon -14 (5,700 years).

Control and disposal of the radioactive gases is an important and difficult aspect of radioactive waste management even though it involves a minor portion of the total radioactivity produced by the nuclear industry.

Data (1967-69) obtained from presently operating plants indicate that on the average plants have released less than five per cent of the amounts permitted under established radiation standards. The average exposure to the total population living within a radius of 50 miles from a nuclear power plant would be only a small fraction of 1 millirem per year. This may be compared to an annual background exposure of almost 100 millirems per year received by the population living at sea level in the U. S.

In order to provide numerical guidance the AEC announced on June 7, 1971, that new plants should be designed to limit radioactivity in effluents to levels that would keep radiation exposure near the plants to less than five per cent of natural background radiation.

A major supplier of nuclear energy in 1971 announced a major advance in nuclear power plant design which eliminates practically all discharge of radioactivity from pressurized water reactors to the environment during normal operating conditions. The new system will allow plant operators to concentrate and contain radioactivity within the reactor system and either store on site or ship it off site periodically for storage. The new design virtually eliminates the release of tritium from the plant during normal operation. The tritium will need only to be shipped off site for storage once or twice during the approximately 40 year lifetime of a nuclear plant.

Another major supplier has also announced the availability of improved waste treatment plant design to reduce the effluent radioactivity level by a factor of 100 below the level obtained by presently operating BWR plants.

The company is presently considering steps concerning additional gaseous emission controls.

The Nature of Radioactive Wastes

Wastes containing radioactive isotopes may be in the form of gases, liquids or solids, may be soluble or insoluble, and may give off various types of radiation at many energy levels. Although many radioisotopes decay rapidly, some require hundreds or even thousands of years to decay to safe levels. With this great variation it becomes obvious that each isotope must be studied individually and handling methods designed to fit the characteristics of that isotope.

The hazards of radioactive materials stem from their basic characteristics. Radiation cannot be detected by the senses except in massive doses. Did you feel any sensation of "penetration" or any noticable effect when submitting to a medical x-ray examination? Radiation may directly damage an individual or, by impairing his reproductive cells, may harm future generations. Fortunately, the nature of radioactivity also makes it possible to detect its presence with certain instruments such as geiger tubes or film badges.

The half-lives of radioisotopes are not responsive to outside influences. Each isotope decays at its own particular rate regardless of temperature, pressure, or chemical action, and continues to do so no matter what is done to it.

ALLOWING RADIOISOTOPES TO DECAY NATURALLY IS THE ONLY PRACTICAL MEANS OF ELIMINATING THEIR RADIOACTIVITY. ALL PROCESSING, STORING AND USE OF RADIOISOTOPES MUST BE THEREFORE CONSIDERED AS AN INTERMEDIATE STEP LEADING FINALLY TO DISPOSAL BY DECAY.

Waste Management

There are two basic principles which are broadly applied in waste management:

1. Dilute and Disperse. Wastes of appropriately low activity may be reduced to permissible levels for release by dilution in air or in waterways. Wherever materials are to be released to the environment, the amount of radioactivity that can be safely dispersed is determined quantitatively for each specific radioisotope.
2. Concentrate and Contain. Radioactive materials can be stored in perpetually controlled sites. The volume of the stored isotope would be prohibitively great if it were not first concentrated. High-level wastes are concentrated and solidified for long term storage. Present technology lends itself to solidification and deep underground storage in stable geological formations such as salt mines.

Sea burial of low level wastes in sealed containers has been halted by the United States, but European nations and Japan still use this method. High level wastes have never been disposed of at sea by the United States.

It is necessary to evaluate each case individually when applying the above principles, and results must be carefully checked. The factors evaluated include accurate data on the specific radioisotopes, their chemical form and concentration, their maximum allowable concentrations for release, and the detailed operating standards established. If conditions change at the site, operating standards must be reexamined and changed if necessary.

Conscientious application of these considerations are mandatory for the success, safety and economy of waste-management activities.

How Much Radioactive Waste Must We Consider?

Year	Projected Power Capacity	Volume of Low Level Waste	Volume Concentration
1980	123,000 Mwe	3.5 million gal.	35,000 ft.^{3}
2000	675,000 Mwe	55 million gal.	550,000 ft.^{3}

The cost of waste handling and processing facilities at nuclear power plants averages only three to five per cent of the total plant cost. The cost of managing high level wastes from fuel processing is expected to be one per cent or less of the total fuel cycle cost.

Gaseous Waste Management

Gaseous wastes may contain natural radioactivity, fission product activity in the elements xenon and krypton, or materials activated by neutron absorption. In the mining, milling and fabrication of uranium into fuel elements, airborne radioactivity consists of natural radioisotopes in dusts or radon. These typically occur in low concentrations. Specialized ventilation of the work area gives adequate protection. Air discharged from mine ventilation systems usually contains radon-222 and its decay products.

The generation of gaseous radioactive wastes at nuclear power plants varies in composition for each type of reactor, but the wastes can be effectively managed in all types of reactors. In general, gaseous wastes of short half-life such as xenon are held for an appropriate period of decay and then are released under controlled conditions through a high stack after filtration.

The release of radioactive gases from operating nuclear facilities has been substantially below limits prescribed by applicable radiation standards. However, as the world's nuclear power production increases, the build-up of ^{85}Kr in the atom may become important. Continued assessment of the future significance of ^{85}Kr to overall radiation exposure is considered desirable.

Cyrogenic (extremely low temperature), absorption methods of removal of ^{85}Kr have been developed which will aid in the solution of this problem.

Radioiodine is often present in gaseous reactor wastes. When it is present it is necessary to include a special removal step, such as passing the gases through activated charcoal, or a chemical-reaction system that converts the iodine into a solid.

The spent fuel elements are usually stored for about six months to allow them to decay to a lower level of radiation before they are shipped to reprocessing centers. Fuel reprocessing plants usually store these elements until they decay even further before reprocessing them.

Liquid Waste Management

Liquid wastes vary greatly in their concentration, from very low level to intermediate and high level concentrations of radioactivity.

Low level wastes have a radioactive content sufficiently low to permit discharge to the environment with sufficient dilution. They have no more than 1000 times the concentration considered safe for direct release. In liquid form, low level wastes usually contain less than a microcurie of radioactivity. (A microcurie is approximately one millionth of the activity of 1 g of radium).

Intermediate level wastes have too high a concentration to permit release after simple dilution, yet they are produced in relatively large volumes. Their radioactivity is approximately 100 to 1000 times higher than that of low level wastes. In liquid form they may contain up to a curie of radioactivity per gallon. They are reconcentrated and treated as high level wastes.

High level wastes contain several hundred to several thousand curies per gallon in liquid form. They usually result from chemical reprocessing of spent nuclear fuels in order to reclaim the usable fuel which remains in the fuel rods after they have been removed from a reactor. High level wastes pose the most severe potential health hazard and the most complex technical problems in radioactive waste management.

Handling Procedures for Low Level Radioactive Wastes

Uranium mines and ore mills produce relatively large quantities of low level liquid wastes requiring minimal treatment.

The treatment of low level wastes of fuel fabricating and reprocessing plants along with laboratory facilities usually includes several or all of the following steps: filtration, chemical precipitation, ion exchange, evaporation, solidification in concrete,or absorption in porous materials such as vermiculite.

Some of the low level wastes may first be accumulated in holding tanks to permit decay of the short half life isotopes. The material is then discharged via a separate sewage system to a settling tank that removes most of the solid material. From here the remaining liquid is discharged through a sand filter, collected in an underlying tile field, chlorinated, and finally discharged into a nearby stream or river with sufficient volume to dilute the wastes to the prescribed levels.

Samples are collected at key points in both the internal system and the nearby environment. These are monitored on a prescribed schedule to assure control.

As the nuclear industry grows this method of discharge becomes unsatisfactory. Because of the large volumes involved it is difficult yet important to develop efficient and economical methods of eliminating even low level discharge to the environment. Present technology allows us to do this.

It is required to decontaminate low level wastes to an extent that would even permit direct consumption of the liquids by humans with no harmful effects.

Handling Procedures for Intermediate and High Level Radioactive Wastes

What procedures are used in the handling of radioactive wastes of higher concentration and activity?

High level wastes from processed nuclear fuels is the most important problem facing the nuclear industry. These wastes produce substantial amounts of heat for a number of years, and therefore handling and storage procedures must include consideration of heat removal at all stages. Furthermore, the long-lived radioisotopes may require hundreds of years to decay to safe levels; during all this time they must be stored away from man and not released to his environment.

Tank storage is a method of storage of high level wastes which have first been concentrated. Tank storage of liquid wastes has proven to be less than satisfactory. Moreover, to extend this to hundreds of years will require periodic replacement of tanks and no valid basis yet exists for accurately predicting tank service life. Experience indicates a reasonable tank life expectation of several decades.

There are over 80,000,000 gallons of high level wastes now stored in A.E.C. tanks at Hanford, Savanna River and Idaho. These installations constitute 95 per cent by volume of all high level wastes in the country. At the present time a program of in tank solidification is being carried out. At the AEC Hanford plant approximately 25 per cent of the tank-stored high level wastes are now in the form of salt cakes and sludges. This is accomplished by reducing the high salt content waste to this form by an evaporation cycle. Stored wastes are first processed to remove the relatively abundant long lived heat generating isotopes Sr^{90} and Cs^{137} in order to maintain the heat generation rate in the salt cake in tolerable levels. The cesium and strontium fractions are being stored in water cooled tanks in cells of the waste treatment plant until a fission product encapsulation and storage plant is completed in 1973. They will then be converted to chlorides or fluorides, doubly encapsulated in a water basin, and finally, when they have decayed sufficiently, transferred to a federal repository for permanent storage.

The bulk of the Hanford high level wastes is expected to be immobilized as salt cakes in the existing underground tanks by 1971.

At Savanna River the possibility exists that the waste may be stored in caverns mined in the bedrock. This method offers a potential of signif-icient cost savings and convenience. Before any decision is made to store wastes in underground caverns a substantial amount of exploration work will be necessary to assure that the wastes will be isolated from the environment for centuries.

Solid Waste Management

Most solid radioactive wastes are things such as gloves, towels, and other items used to handle radioactive materials, and are of moderately low level. They are disposed of by burial in unlined pits and trenches. The

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materials are usually packaged in metal drums of some sort. Several feet of earth are placed over the pits and hold surface radiation levels so low that exposure for a full year would result in less radiation than results from a typical medical fluoroscopic examination. Burial sites are carefully selected, and arrangements must be made to control wastes over a period of many years after they are buried.

During the past 25 years the principal AEC installations have operated and maintained suitably located land burial grounds at Aiken, South Carolina, Idaho, Richland, Washington, Oak Ridge, Tenn., Los Alamos and Sandin, New Mexico, the Nevada Test Site and Range, Nevada, Portsmouth and Paducah, Kentucky. These operations use conventional sanitary land fill procedures similar to that used for municipal refuse disposal.

Some of these facilities are operated by commercial companies but all are on federally owned and controlled land and are subject to federal regulations.

High level solid waste storage requires more shielding and deeper burial sites. Natural geological formations most suitable probably are salt formations. They are usually dry, are impervious to water, and are not associated with usuable groundwater sources. The ability of salt to change shape under pressure causes rapid closure of the holes. Salt is sufficiently strong that large cavities formed by mining will not collapse. The only remaining problem is convincing the public and the officials of the political subdivision in the vicinity of potential storage areas that the storage sites will not be detrimental to public health and land values.

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AEC AND INDUSTRIAL RADIOACTIVE SOLID WASTE BURIAL SUMMARY (10^3 CUBIC FEET)

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1962	2359	--	2359
1963	1801	156	1957
1964	1715	338	2053
1965	1454	465	1919
1966	1413	494	1907
1967	1695	619	2314
1968	1746	718	2464
1969	1565	647	2212
1970	2007[4]	860	2867

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[1] FISCAL YEAR IS FROM JULY/JUNE.

[2] FROM AEC CONTRACTOR OPERATIONS, INCLUDING OTHER GOVT. AGENCIES & LICENSEES (1961-64).

[3] FROM ALL SHIPPERS (AEC CONTRACTORS, OTHER GOVT. AGENCIES, LICENSEES & OTHER SOURCES).

[4] INCLUDES ~400,000 CF OF OFF-SITE, NON-OPERATIONAL WASTES.

Radioactive Wastes in the Immediate Vicinity of Nuclear Power Plants

The quantities of radioactivity discharged from nuclear power plants are well below legally permissible release limits. Reactor installations generally control their radioactive wastes in accord with the strict standards applying to unidentified mixtures rather than the less stringent ones for individual radioisotopes.

No liquid wastes are released into the ground at the reactor installations. The waste systems use decay hold up tanks, evaporators, ion exchange systems, and various gas control systems. In a typical water cooled reactor all radioactive wastes originate in the reactor and its coolant system. When necessary, contaminated liquids are processed in evaporators or ion exchangers. The evaporator concentrates and the used ion exchange resins are then retained for later shipment from the site as solid wastes. Ion exchange is typically used for continuous cleansing of reactor coolants, but discharged reactor water must nonetheless be retained in tanks to allow radioactive decay and other types of treatment.

Radioactive wastes are generated in all areas of the nuclear fuel cycle, and accumulate as liquids, solids, or gases at varying radiation levels. The wastes which cause the greatest concern are the high-level wastes. High-level wastes are those which by virtue of their high radioactivity, long half life, and biological effects, require perpetual isolation from the environment. The reprocessing of spent fuel elements is the primary source of all high-level wastes.

It has been estimated that by the year 2,000, 77 million gallons of high-level liquid wastes will have been generated by the civilian nuclear power program. This will be solidified, reducing the volume, but the total amount of solid wastes by the end of the twentieth century is projected to be 4 million cubic feet per year.

These wastes must be isolated from man and his environment until their intense radioactivity is reduced by radioactive decay. The modern concept in handling these wastes stresses that they must not merely be disposed of, but must be stored underground in geologically tight formations, and kept under perpetual surveillance.

Comparisons of various geologic formations led to the conclusion that bedded salt formations showed the most promise for the storage of high-level radioactive wastes, for the following reasons:

1. Bedded salt formations are practically always dry, impervious to water, and not associated with usable sources of ground water.
2. Salt has considerable compressive strength, being similar to concrete in this respect. The bed remains structually sound even when large spaces are mined out.
3. Extensive salt beds are available. An area of 400,000 square miles in the United States is underlain by salt beds. Only about 3,000 acres of salt area would be required for disposal purposes by the year 2,000.

The methods and concepts of perpetual isolation of high-level radioactive wastes were demonstrated by Project Salt Vault, a demonstration storage of high-level radioactive solids in a Kansas bedded salt mine.

On June 17, 1970 the Atomic Energy Commission announced tentative selection of a site near Lyons, Kansas, f location of a demonstration repository. It is probable that this repository - constructed in a deep bedded salt formation - will be designated as the initial Federal repository for solid radioactive wastes.

Heat as a Waste Product

Does nuclear power production create a special *"burden"* on the environment in regard to the disposal of unused heat in the power production process?

Most of the energy used by man is provided through the process of converting heat energy into electrical and/or mechanical energy. The efficiency of this conversion is limited by natural laws of conversion, efficiency, and friction. Modern steam turbine equipment provides probably the highest efficiency of all the heat engines in practical use today. Using high temperatures of 1000° to 1100° F and steam pressures ranging from 1800 to 3500 lbs. per square inch, today's modern fossil fueled steam-electric plants will attain an overall thermal efficiency of 37 to 38 per cent. However, less than one-half of the presently operating plants attain this thermal efficiency. The *average* of all fossil-fueled plants operating at the present time is only about 33 per cent efficiency.

Because of certain design criteria, most nuclear power plants produce steam at lower temperatures (of about 500 to 600° F) and at lower pressures (of about 800 to 1000 lbs. per sq. in.). Thus the thermal efficiency is somewhat lower, approximately 32 per cent. Advanced gas cooled reactors presently in the design and testing stage are expected to match or better the thermal efficiency of the best fossil-fueled plants. The Fort Saint Vrain high temperature gas cooled reactor scheduled for completion in 1972 is expected to produce 330 megawatts of power and to have an overall net plant efficiency of better than 39 per cent.

The thermal efficiency of nuclear power plants now in service, while lower than that of the *"best"* fossil-fueled plants, is about equal to the *"average"* of all fossil-fueled plants now in operation.

The balance of the energy from all types of power plants, which amounts to 60 to 70 per cent of the total available energy, must be dissipated to the environment as heat. Fossil plants discharge about 15 per cent of the waste heat into the air with the flue gas. The remaining 85 per cent of the waste heat is discharged into a cooling stream of water. Nearly 100 per cent of the waste heat from a nuclear plant is discharged into the cooling water stream. The ultimate step in any heat rejection process by the environment itself is by radiation of heat to outer space.

The problem then, of *"thermal Pollution"*, *"thermal effect"*, *"thermal enrichment"*, or whatever name you choose to give it, is with us in fairly equal quantities from any method of power generation, nuclear or fossil-fueled plants.

Comparison of Cooling Water Needs

Fossil	30-40 gal/kwh
Nuclear	55 gal/kwh

Are there any beneficial uses for this waste heat being developed?

The continued growth in demand for electricity affords an interesting new opportunity in utilizing waste heat in beneficial projects. In general it appears that the most promising projects for utilizing waste heat are biological and biochemical processes, with chemical and physical processes being of descending order of merit.

A current study is investigating the beneficial uses of low grade heat in compatable urban systems. One example is the use of discharge heat to increase the rate and effectiveness of secondary sewage treatment processes. The activated sludge process used in many of these systems can be induced to proceed at almost double its normal rate by increasing the temperature by approximately 25 F. Alternately, treated sewage water effluent may be used in cooling towers and the nutrients can be substantially concentrated by the evaporation of excess water. If the evaporated water could be condensed and collected it could become a source of pure water. The nutrients can then be recovered and recycled in man's environment. The desalination of sea water could provide pure water and the dissolved minerals used as a by product. Also controlled heated water has been found to be advantageous in a few forms of fish culture, particularly shellfish, and in agriculture to extend growing seasons. In both cases growth is accelerated with heated water.

These concepts and many others are incorporated into the idea of the Nuplex or Energy Center complex. Unnder this concept an entirely new city would grow up associated with and complimentary to a nuclear electric power source. Practically all of the waste heat would be used for beneficial purposes. However, no such cities exist at present.

The discharge of heated water into natural water systems has not produced major problems as yet, but continued growth in electrical power production well may cause damaging environmental stresses to occur in some areas unless heat loss is controlled. Through a detailed examination of the physical, chemical and biological factors integrated in a total systems analysis, an assessment of environmental impact of discharge heat must be made on a case by case basis.

> *If trends of the past twenty years persist for another 10-15, 1/4 of the natural fresh water runoff of the United States could be employed in the cooling of Electric Power Stations. But since much of the runoff occurs in the short flood season, the relevant number for 1980 is actually 1/2 of the normal flow.*
>
> *Projecting this same trend for thirty years, (to 2,000), the equivalent cooling demand will correspond to raising the annual runoff of the United States by 20 degrees."*
>
> *John P. Holdren*
> *Thermal Pollution and Controlled Fusion*

Alternative Methods of Heat Disposal

Cooling Ponds and Lakes

The cooling system for some reactors may be a pond or lake into which the secondary cooling loops of a reactor may extend. Water in the reactor loops transfers its heat into the water. Eventually this heat must be lost into the atmosphere by the pond. One disadvantage of ponds is the large acreage required both for storage and drainage.

Cooling Towers

Waste heat may be transferred to the air through two types of cooling towers - the evaporative type, or wet cooling tower which loses heat by means of evaporation, and the dry type which gives up its heat by air convection, in the manner of an automobile radiator.

Wet cooling towers for a 1000 megawatt nuclear plant may evaporate up to 20 million gallons of water per day. A comparable fossil-fueled plant would evaporate about 14 million gallons. This excess water burden in the atmosphere may effect local climactic conditions in the form of increased fog or sleet. Careful local studies are required before cooling towers are erected.

Dry cooling towers avoid the problems of fogging and icing common to wet cooling towers, since they have no routine water loss. They are of low efficiency and so cut down the power plant efficiency. Dry cooling tower technology has not been demonstrated in the United States.

Once-Through Systems

In this type of system water is drawn in from a lake or stream, used to cool the condenser, and then released back into the stream via cooling canals, at a higher temperature. The stream eventually loses the heat into the atmosphere. This is the least desirable and most damaging type of cooling system.

Conclusion

This heated water may be critically low in oxygen, and may favor the rapid growth of some aquatic plants. This change in temperature, if excessive, may cause critical ecological problems. Because of this, once-through systems are the least desirable type of cooling.

The alternatives listed here may be applied to individual plant situations, but they still do not constitute a satisfactory answer to the heat problem. The most desirable answer will be either to find a use for the excess heat, such as in desalination of sea water, heating greenhouses, and the like, or, even more desirable, to increase the efficiency of electrical generation. At the present time the best of our generation facilities are about 40 per cent efficient. This means that 60 per cent of the heat produced must be lost as thermal pollution. A process called magnetohydrodynamics promises to increase this efficiency to 60 per cent when fully developed.

CHAPTER 5

PLANT SITE CONSIDERATIONS

What are your first thoughts when you pick up the newspaper and read the following headline:

"Nuclear Power Plant to be Built on Local Site"

If you are like most people, this announcement may invoke some anxiety and fear. *"Why do they have to build a thing like that here?"* you might ask.

It would be most desirable to be able to pick a site that would in itself solve all of the environmental problems associated with electrical power generating plants but such cannot be the case.

In this chapter we will explore the criteria and problems involved in the selection of power plant sites.

Siting Concepts

A number of siting concepts have been proposed and studied. Many of them offer positive advantages for minimizing adverse environmental effects.

Traditionally power plant sites have been located on the surface of the ground, either near the source of the mineral resource (coal, water, gas, natural steam, oil) or in close proximity to the urban market and major transmission lines. These sites were seldom picked in reference to overall environmental quality protection. They were selected for economic reasons.

In most cases the power plants you see today had their locations based on either the proximity of the natural resource or the urban market. In general, these locations were selected with disregard of environmental pollution and its effects upon people.

Offshore Siting

The use of offshore sites adjacent to coastal cities has been proposed. These sites would alleviate the problems of land availability, esthetic compatability, and provide adequate cooling water. In addition these offshore sites could be located close to the major market areas of the east and west coasts.

Nuclear power plants could be built on a massive steel-and-concrete barge, 400 by 400 feet or 150 by 900 feet. A nuclear steam-generation plant on the barge would rise 175 feet above sea level, protected on four sides by a breakwater enclosure.

The breakwater enclosures resting on the sea bottom would have walls 100 feet thick and would rise 60 feet above the sea's surface. They would be designed to protect the plant from all natural perils such as hurricane whipped seas or stray ships.

Cables carrying the power from plant to shore would be entrenched below the sea bed.

Underground Sites

Underground hydro-electric power plants were built in Sweden long before World War II. Costs of underground excavation have risen only slightly in spite of a fourfold rise in surface construction costs. Economic reasons themselves usually justify subsurface construction. Other advantages include safety and the environment. Sometimes underground locations are based more on environmental requirements and landscape shortage than on strict economy.

Nuclear power plants are playing a more and more important role as suppliers of base power. This role makes their location close to large urban and industrial concentrations desirable. This location close to the city center, in turn, makes underground construction very attractive.

Plants could be located deep in rock in the immediate vicinity of a large urban center. There could be separate caverns for the reactor with its auxiliary systems and fuel storage and for the turbine units. The reactor structure could be sunk into a pit some 150 feet below the floor of the reactor cavern. These caverns would then receive a concrete lining and be further strengthened in the reactor pit using a welded sheet-steel lining surrounded by concrete.

This type of installation has been referred to as the Energy Center Concept. This underground facility would serve as the energy nerve center for an entire urban and industrial complex of hundreds of thousands or millions of people.

Pumped Storage of Electricity

Pumped storage facilities utilize the potential energy stored in water which is lifted to high reservoirs by electric pumps energized during hours of low electrical demand. By reversing the process, the water is released to turn hydraulic turbines, producing power during times of peak load electrical demand. While such systems enable a high utilization of power plant equipment elsewhere in the utility system, losses in the process amount to above 25 per cent; that is, for every four kilowatts used to pump the water, only three kilowatts are later recovered.

This type of facility is particularly well suited for large communities with a concentration of industry and a heavy demand for power.

Criteria for Power Plant Site Selection

Site Access

Will it be possible and economically feasible to bring construction equipment and power plant machinery to the proposed site over existing

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highways, railroads, or water routes? Further, will it be possible or economically feasible to bring in the massive generators and, in the case of a nuclear plant site, the reactor and containment vessel?

A ready access to a site is highly important, and one of the first factors considered after the decision is made on the plant type and general location.

Natural Environmental Factors

Natural environmental factors may greatly influence a power plant siting decision. The three most important factors under this consideration are the ecology, the geology, and the meterology of the site. Any one of these factors may be critical enough to rule out an otherwise potential site.

General Ecology

Ecology is that branch of science that deals with the inter-relationships between organisms, including man, and environment. A complete understanding of the almost infinite number of aspects of the environment is virtually impossible but some reasonable level of understanding must be attained so that future power facilities can be sited and operated without excessive degradation of the environment. The following ecological research is critical to the alleviation of power plant siting problems:

1) Improved techniques must be developed to determine the health and age of ecosystems so that we can predict accurately the changes which may result in any given ecosystem through even a slight alteration of the environment.

2) Certain animals and plants are pollution indexes and as such should be monitored. These organisms indicate the presence of certain pollutants in the environment.

3) Cumulative effects on distant ecosystems must be watched closely. A distant ecosystem may actually be the critical system upon which to base pollutant release rates. For example, the Chesapeake Bay as an ecosystem serves as a sink for pollutants released in many inland watersheds. If several nuclear power plants are sited along the Susquehanna River, the Bay area may be the critical system upon which to base pollutant release rates for each of the nuclear plants on the Susquehanna.

4) Detailed models should be developed which can be used in simulation experiments to predict the environmental effects of particular power plant effluents and effluent levels.

Geology

Power plants are extremely heavy structures with very low settling tolerances. The underlying bedrock must be extremely solid, and must not allow water to pass through it easily.

The probability of the occurence of an earthquake and its potential strength must be taken into account in the selection of a power plant site. Current practice in the selection of sites for nuclear power plants is based upon the knowledge of earthquake potential available plus a large safety factor. Nuclear plants are not located on or in the immediate vicinity of faults which are considered at all likely to display any earthquake activity. An earthquake risk map has been developed for the entire United States and should prove a valuable aid to those involved in plant siting decisions.

Large quantities of water are needed in todays power plants for cooling and waste heat disposal. It is necessary then that a plant site must be near a source of water that meets the needs of these plants. A detailed study of the surface and ground water must accompany any site evaluation.

The use of cooling towers would reduce water needs.

Information on the cooling capacity of surface water and ground water bodies is necessary for a siting decision. This information can then be used to determine the number and location of power plant sites along any major river, lake, bay or over any major underground source.

Cooling towers, which transfer heat directly into the atmosphere on the plant site, are considered in all new power plant installations and are frequently installed in areas of water scarcity.

Meteorology

In addition to reducing and controlling the release of air pollutants from power plants to the environment, it is necessary to establish that a site has weather conditions suitable for a power plant. Such a determination requires an evaluation of the air pollution potential of the site and many weather and climate factors. Pollutant concentrations must be predicted for a range of weather conditions. Models based on correlation of pollution concentrations against weather conditions must be used. In general, air pollution problems at nuclear plants are minimal. Significant airborne radioactive wastes are contained at the plant site and not released to the environment.

Air pollution is a most important factor in siting fossil-fueled plants. Existing power plants contribute to our air pollution problem primarily through the emission of particulate matter and sulfur oxides, and oxides of nitrogen.

Population Density and Land Use

Environmental concern extends to esthetic and economic objections to the use of choice land for power plants and for transmission lines.

A 1,000 megawatt nuclear installation now requires about 500 acres while a similar coal plant with on-site coal and ash storage facilities could require up to 1,200 acres. The nations overhead electric transmission line rights-of-way already require nearly 4 million acres of land, and this total is growing each year.

The Atomic Energy Commission's Code of Federal Regulations, Part - 100 of Title 10 provides criteria for determining an exclusion area surrounding a proposed plant, a low population zone immediately surrounding the exclusion area, and a population center distance representing the distance from the plant to the nearest boundary of a densely populated area containing more than about 25,000 residents.

Environmental Impact Evaluation of Plant Site Selection

All steam-electric plants as well as other installations using fossil or nuclear fuels will have some adverse effects upon the environment. With the proper selection of sites, appropriate design of facilities, and careful pre-construction and post-construction studies, much can be done to reduce such effects.

Air Quality

A) Determine present population distribution and expected growth patterns; determine existing and expected industries in the area and likely emissions to the air.

B) Consider factors of land surface affecting dispersion of air emissions; make measurements of prevailing wind directions and velocities, ambient temperature ranges, precipitation values, and factors related to temperature inversions;

provide for air monitoring before plant startup and after plant operation - measuring wind direction and velocity, temperature, sulfur dioxide content, nitrogen oxide content, particulate content, dust fall, and haze.

Water Quality and Quantity

A) Determine quantity availability for once-through cooling water system; or for cooling towers where water supplies are limited; determine available average and firm flows in streams to be used to supply cooling water; determine available ground water supplies.

B) Measurements must be made on physical and chemical properties of water.

C) Algal studies, large invertebrate animal studies, fish population studies, and any unique or significant ecosystems studies should determine species and quantities present at proposed points of intake and discharge of cooling water supplies before and after plant startup to determine their seasonal variations and the environmental effects of plant operation.

D) Temperature prediction studies are necessary to demonstrate the ability of cooling water systems to meet surface or ground water temperature standards.

Radioactive Wastes

A) Proposed releases must be determined based on site conditions, including background radiation, weather characteristics, and related factors; measurements and studies necessary to predict the effects of project construction and operation on the environment must be made.

B) Monitoring programs must be set up; stations should be selected to measure radiation where maximum effects of the plant operation are expected and also where background radiation can be determined; the following materials should be sampled in the region of the site to determine the level of radioactivity - airborne dust, precipitation, milk, external radiation, waters and sediments, and water organisms.

Land Use

A) Sufficient acreage must be made available, and in the case of nuclear plants must be according to AEC regulations; the relationship of nuclear plants to population centers must be in accord with AEC regulations.

B) Study physical characteristics of the site; determine the incidence of flooding or wind storms.

C) Determine relationship to all historical, archeological, or cultural areas in the site region; closeness to and effects on these areas.

D) The plant site should conform with adopted state and regional land use plans; full consideration should be given to recreational and other compatible uses of the plant site; visitor centers and other facilities to accommodate the visiting public should be provided.

E) The architectural design should blend with the surrounding area accompanied by blending landscaping.

Governmental Standards on Plant Siting

Existing

Neither the environmental protection agencies nor the state utility regulators have authority or procedures to resolve the particular environmental problems of large power plants and transmission lines in a timely fashion prior to construction. The existing institutional arrangements come to bear too late to accomplish the twin goals of environmental protection and adequate energy supply.

The following laws and regulations are in effect as of June, 1972.

a) National Environmental Policy Act of 1969, P.L. 91-1190

b) Clean Air Act, as amended, (Federal)

c) State's Clean Streams Acts

d) Federal Water Pollution Control Act as amended

e) Federal Water Quality Act of 1965

f) Water Quality Improvement Act of 1970 (Federal)

g) Atomic Energy Act of 1954, as amended (Federal)

h) AEC Regulatory standards and licensing requirements as published in 10 CFR Chapter 1.

i) AEC *"Reactor Site Criteria"* regulations are contained in 10 CFR Part 100.

j) Fish and Wildlife Coordination Act (48 stat. 401, as amended; 16 U.S.C. 661 et seq.)

k) National Historic Preservation Act of 1966, P.L. 89-665

l) State Fish Commission rules and regulations

m) Federal Power Act, 16 U.S.C. 791-825r.

State and local regulation of power facilities, in most instances, means only that an air and water quality agency gives its approval. Rarely does any state currently exercise control over the siting of electric power plants and the routing of transmission lines, but this situation is rapidly changing.

Proposed
Federal Legislation:

a) All public utilities must publish a long-range plan.

b) Primary and alternative sites must be made known to the public 5 years in advance of construction; detailed plans for new power plants to be published two years in advance of construction with all environmental protection facilities outlined.

c) Each state must establish a state agency to approve all new power plants and transmission lines far in advance of construction.

d) Regional agencies may be established instead of individual state agencies.

e) Utilities would be given the right of eminent domain to acquire plant sites for all bulk power facilities approved by the state or regional agency.

The average nuclear plant must get in excess of 100 state and federal permits to become operational.

CHAPTER 6

THE ENVIRONMENTAL IMPACT: A COMPARISON OF FOSSIL AND NUCLEAR PLANTS

The generation of electric power, like any system of energy conversion, or any human activity for that matter, involves some environmental cost. Different styles of power generation produce different effects in the diverse parts of our environment. In this section we will consider the environmental cost to land, water and air by the generation of power by conventional means such as the burning of coal, oil and gas, and by nuclear means through the fissioning of a heavy nucleus. The biological effects of each method will be covered in the next section of the material.

It is the intention of this Section to show the student the environmental effects of power generation in sufficient detail to allow him to consider the assets and debits of the two general types. The use of the word *"environmental"*, in this section, refers to nonbiological effects on man. These effects include; the irreversible consumption of natural resources, the effects of extracting these resources from the earth, the fate of waste products, the physical space required for the plant and fuel storage, constructions of transmission lines, transportation of fuels, the effects of plant emmissions, and the aesthetic impact of the plant. Four choices are available as to the most desirable style of power generation: 1) fossil fuel only, 2) nuclear only, 3) some mix of the two, 4) stop power plant increases. The student should realize also that the resources used in both methods are finite. Electricity is also a resource and strong considerations should be given to its conservation.

Effects on Land

Conventional Power Generation

Conventional generation uses the process of burning natural carbon-containing materials, called fossil fuels, for the production of heat and steam. These fossil fuels include coal, oil, and natural gas. These materials are called *"fossil"* fuels because they were formed from the bodies of ancient plants and animals. The organisms were subjected to pressure over very long periods of time until the materials assumed their present familiar forms.

These fossil fuels are a kind of energy savings account set up in nature millions of years ago. The energy we derive from them today is really solar energy deposited in those ancient plants.

The term *"conventional"* is used because this method of heat and steam generation to make power has been in most widespread use since the beginning of the electrical era. Besides hydroelectric generation, fossil fuel generation was the only practical method known until the fission method began to be developed in the mid-1940's.

On the earth, all mineral resources are limited. Just as we only have so many tons of copper and tin in the world, we only have so many gallons of crude oil and tons of coal. We can make gas from coal and oil but the whole group of fossil fuels taken together is of finite supply. These resources are no longer being produced in nature at any appreciable rate.

These fuels are useful for many purposes beyond burning for electric power production. They are used to make fuel oil and gasoline which are, at this time, very necessary to personal, public and commercial transportation.

They are used widely in homes for space heating and cooking. They are used in making many chemicals which in turn are used to make synthetic fabrics, paints, plastics, and other apparent necessities of a growing population.

It is possible that these fossil materials will be used to make food in the future, either out of choice or out of necessity.

You can see that these fossil materials are useful and necessary for a wide variety of human needs. There are many uses for them beyond burning for production of electrical power.

Fosil fuels are claimed from the earth. Coal is mined in many parts of our country and throughout the world. Oil is pumped from the earth in a variety of locations. Natural gas is usually found in connection with oil deposits. The claiming of these resources and their transportation to the place where they will be used has an environmental cost.

Coal is removed from the earth by deep mining or by strip mining. In deep mining, the men and equipment go hundreds or even thousands of feet underground to the coal vein. The coal is broken up and lifted to the surface. In strip mining, the coal deposit is closer to the surface. It is mined simply by stripping the earth thus exposing the coal vein. The coal is then milled and cleaned, and moved by truck or train to a supplier or to the power plant.

In the course of removing the coal and following the depletion of the coal deposit, a number of things happen to the environment. The most obvious effect is that which we see in careless strip mining. Vast areas of countryside are dug up to remove the coal. In the past, the soil was not replaced and replanted with trees and grass. A trip to the long time coal producing areas will show you the great devastation produced by strip mining. This effect is not only an eye sore, but also a loss of otherwise useful land, a contributor to flooding and stream contamination.

Another effect of both deep and strip mining is acid-mine drainage, a kind of water pollution. This effect comes about by a chemical reaction among water, air and iron pyrites in the mine diggings. The reaction makes a mixture of acids plus iron salts. The mixture leaks into the stream. These impurities in sufficient concentration produce a stream environment in which it is impossible for fish and most life forms to survive. Streams polluted with acid mine drainage look rusty on the bottom, and taste sour, something like vinegar. They may not be used for drinking purposes without extensive treatment.

It is going to take much effort and billions of dollars to pay for the use of coal over the last century. The reclaiming of coal land in Pennsylvania in 1964 cost as much as $800.00 per acre.

Fortunately, laws are on the books in some states which will discourage these abuses in the future. Other states still need such laws.

The production and transportation of oil for power generation and other energy uses has well known environmental costs. The best known of these costs are oil spills.

Oil is pumped from the earth either from land surfaces or from under the sea. Natural gas is frequently produced along with oil. The oil is transported by truck, train, tankers, barges, and pipe lines. The gas is usually transported by pipeline.

At the point of production, we see the first probable effect of oil use. Occassionally defects in the pumping mechanism occur, producing oil spills on land, and oil slicks on the water. These result in a hazard to the plants and animals in the area. An example of this damage was the Santa Barbara oil spill in 1969 where thousands of water birds died as a result of oil contamination. The nearby beaches were ruined.

In the transportation phase, we have experienced tanker accidents and pipeline ruptures with the consequent uncontrolled release of oil and oil products.

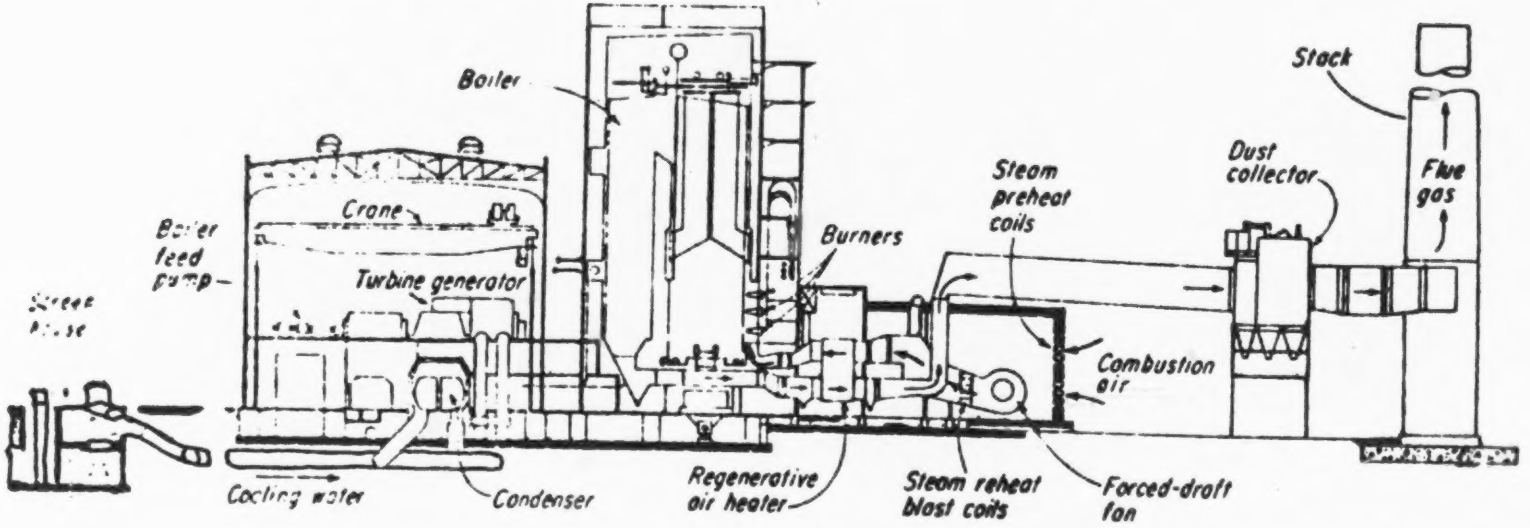
Boiler
Stack
Dust collector
Steam preheat coils
Flue gas
Crane
Burners
Boiler feed pump
Turbine generator
Screen house
Combustion air
Cooling water
Condenser
Regenerative air heater
Steam reheat blast coils
Forced-draft fan

Fig. 1b

FOSSIL – FUELED POWER PLANT

Land Requirements for Generating Stations

The total land space required for a conventional power plant varies somewhat with the type of plant. The space needed for the conventional station includes:

1) the power house itself.
2) on-site fuel storage.
3) on-site waste ash storage.
4) environmental protection equipment such as cooling towers and equipment for the cleaning up of stack discharges.
5) switch yards for transmitting the power from the plant.
6) parking lots, offices, and other support facilities.

A comparison of land area requirements for different types of plants is given below. These examples are for power stations of a 1,000 megawatt capacity.

Plant Fuel	Number of Acres Required
Coal	900 - 1200
Oil	150 - 350
Gas	100 - 200
Nuclear	300 - 900

One reason that the coal fired station requires so much more space is that at least 90 days supply of coal must be stored on site, along with the eventual waste ashes. A modern plant will burn 8,000 to 10,000 tons of coal per day. A 1,000 megawatt station normally requires a reserve storage yard of 20 to 30 acres with the coal piled 40 feet high. Add to this the waste storage problem. Over the station's 35 year life, the

1,000 megawatt station would generate enough ash to cover 150 to 200 acres (a good size farm) to a height of 25 feet. The train yard for the delivery of the coal also consumes much land area.

Oil and gas fired facilities are usually supplied by pipe line, and therefore require only modest on-site fuel storage.

Although natural gas powered stations would require the least land area, and also use the lowest pollution fuel, a lack of adequate gas reserves does not encourage the wide use of gas in power generation. When gas is used, the station is frequently convertible to oil and/or coal at times when gas is not available.

Nuclear Power Generation

Nuclear power generation uses the energy released in the fission of atoms of uranium to get heat. Conventional power generation uses the burning of coal, oil and gas to get heat.

The total quantity of uranium in the world is limited, just as the total quantity of fossil fuels is limited.

Its use as a fuel for reactors and its use in nuclear weapons seem to be the only significant uses of uranium. It obviously cannot be used to make the variety of materials that can be made from fossil fuels.

Although, in a regular reactor, once a uranium atom is used it is gone forever, in the breeder reactor more fuel is made than is used. In effect, fuel can be made to make even more fuel. But even this process can not go on forever because only a limited quantity of the high grade natural uranium ore is present in the world to begin with.

Uranium is found in ore deposits throughout the world. Useable uranium deposits are much less numerous than are fossil fuel deposits. The total quantity of uranium, in terms of tons, is much less than the total quantity of fossil fuels. Uranium occurs in several main types of ores. The ore is mined from the ground. As with any other ore, the raw stuff is milled and the higher grade ore separated from the other minerals. The higher grade ore is then cleaned chemically, and is converted to uranium oxide or *"yellow cake"*. The *"yellow cake"* is, in turn, converted to the gas, uranium hexafluoride, for passage through an *"enrichment"* facility. The *"enrichment facility"* serves to increase the concentration of Uranium-235 isotope in the uranium hexafluoride gas. This increase in concentration is necessary to make the produced fuel useable in the reactor. The *"enriched"* uranium gas is then converted back to a solid, UO_2 and made into fuel rods.

The mining and refining of uranium have definite environmental costs. The first cost is the accumulation of piles of *"uranium tailings"*, the wastes from the refining processes. These radioactive materials have been found to be washed by rain into surrounding streams, thus producing radioactive pollution. These tailings have been used in the past in some areas as land-fill materials around houses, thus providing unnecessary radiation exposure to people.

In the case of the nuclear power site with a capacity of 1000 megawatts, the land requirement runs between 300 and 900 acres. It is equal to or less than a coal plant of the same capacity. The area required for fuel storage is very small compared to conventional plants. The only storage facility needed is a well designed storage vault for new and used fuel. The rate of fuel use in a reactor is about 30 tons over a three year period, compared to over 15 million tons required for a coal plant. The large site area required for a nuclear generator is, therefore, not for storage of fuel and waste. It is necessary for providing distance between the reactor and people. This distance is called an "*exclusion*" distance and is required by law. It provides a protective factor between the public and the reactor in the event of a reactor accident. At nuclear stations, this "*exclusion*" distance runs between 1200 and 4400 feet.

Effects on Air

Conventional Power Generation

Each of the fossil fuels produces its own mixture of air pollution. The chart below shows the amounts of each air pollutant put out by coal, oil, and gas-fired stations. The figures relate to a 1000 megawatt plant.

Pollutant	Pounds Per Year		
	Coal	Oil	Gas
Carbon monoxide	1,150,000	18,400	-------
Hydrocarbons	460,000	1,470,000	-------
Nitrogen oxides	46,000,000	47,800,000	26,600,000
Sulfur oxides	360,000,000	116,000,000	27,000
Particulates	9,900,000	1,600,000	1,020,000

(In the table the data for coal assumes particulate control only. The data assume on air pollution control equipment. These conditions are realistic for the current state of the art.)

So 1000 megawatts generated by coal will cost you about 417 million pounds of pollution in the air per year. An oil fired plant of the same size will cost you about 167 million pounds. A gas fired plant will cost you 28 million pounds.

It is not scientifically correct simply to add these quantities of pollutants together, when considering their effects. Later discussion of life effects will show that one plus one may not add up to two. In this case one plus one may be equal to three or more.

In addition to these traditional chemical pollutants, recent Public Health Service studies show that coal fired plants emit some radioactive material. Naturally radioactive materials such as uranium and thorium are distributed throughout the earth's crust in very small quantities, even in coal. When the coal is burned, some of these radioactive materials are released to the atmosphere. In one study conducted a coal fired plant released more biologically significant radioactivity to the atmosphere than a pressurized water reactor, but less than a boiling water reactor.

Another type of air pollution emitted peculiarly by conventional power plants is atmospheric thermal pollution. A 1000 megawatt conventional plant puts out about 1 million BTU of heat per hour up the stack.

The most widely known air pollutant produced by the burning of fossil fuels is sulfur dioxide (SO_2). Its biological effects on people have been discussed. The effects of SO_2 are usually considered as in the presence of particulate matter or smoke, since SO_2 and smoke usually occur together. Their effects include a reduction in visibility through the atmosphere, an increase in the corrosion rate of metals, and an injurious effect on plants. These effects are seen when the SO_2 concentration is about 0.1 parts SO_2 per million parts air, or less, with an equal concentration of particulate in the air. It is not uncommon to encounter these conditions in the environment.

The next most significant air pollutant from fossil fired plants is the class called nitrogen oxides (NO_x). The effects of this agent include stress corrosion and failure of electrical components and possible fading of certain types of fabric dyes. This pollutant also plays a significant and complex role in the formation of smog.

One type of smog is produced by the interaction of nitrogen oxides hydrocarbons and sunlight. One of the effects of this kind of smog, is injury to vegetation. The extent of damage is tied to the temperature, humidity, and light level to which the plants are exposed. Rubber and certain fabrics may also be attacked by this type of smog.

Although it is difficult to determine in dollar terms the cost of the air pollution caused by fossil fuel burning plants, it has been estimated by a Committee of the National Research Council, that the cost of all air pollution is about $13,000,000 per year or $65 from each of us, in the form of cleaning bills and other damages. This does not include health costs, which are impossible to estimate.

Nuclear Power Generation

Nuclear reactors do not contribute to the load of conventional air pollutants in the atmosphere. The materials routinely released to the atmosphere are radioactive gases of such low concentration so as not to produce a visual impact, nor to damage crops and materials.

Effect on Water

Conventional Power Generation

Two classes of water pollution occur at fossil fuel generator sites: Thermal pollution and chemical pollution.

The thermal pollution, amounting to 4600 BTU's of heat per kilowatt hour electricity produced, originates in the cooling of the plant's condensers. As the river water moves through the condensers, the tiny life forms in the water may be damaged or killed. The discharged heated water may have a lower concentration of oxygen, a condition which may affect water life. In addition, the heated water discharged to the stream water may accelerate the effects of other pollutants already in the river. The part of the river that is heated also may act as a barrier against fish migration.

In some states, thermal pollution of surface waters is reduced by the use of cooling towers. These devices cool the heated water by the passage of a stream of air over falling, heated water. The water is cooled by evaporating part of the water. The water vapor is consequently lost from the body of water. The water loss may be about 10 million gallons per day for a 1000 megawatt fossil fueled plant. This evaporated water may affect local weather patterns to some degree. An alternative to cooling towers is the use of cooling ponds. This cooling method requires about 3000 acres of water surface per 1000 megawatt plant, where cooling towers for the same size plant would require only about 30 acres of land surface.

The sources of chemical pollutants include trace minerals washed from the coal piles and the ash dumps on the generator site. Occasionally, chemicals used in plant up-keep are also discharged into the water environment.

Nuclear Power Generators

Nuclear power plants, like fossil fuel power plants, discharge heated wastes and chemicals. In addition, they discharge small quantities of radioactive materials to the water environment.

In the area of thermal pollution, a reactor will discharge about 40 per cent more waste heat to the water, but will release very little heat directly to the atmosphere, than will the same size fossil fuel plant.

Any device used to reduce thermal discharges to the water, must be 40 per cent larger in a reactor than in a conventional plant. In addition, 40 per cent more water will be evaporated.

The quantities of chemicals discharged from a reactor are comparable to a conventional plant. A reactor, though, does not store coal on site, nor does it store ash. Consequently, the reactor does not contribute trace mineral pollution to the water environment from such sources.

In addition to the aspect of thermal pollution, and chemical pollution which are common to both types of generators, the reactor discharges small quantities of radioactive materials to water environments. In all the operating power reactors, no effect has been observed in the health of aquatic life. There has been no known effect in the commercial use of this water, nor has any aesthetic effect been observed.

CHAPTER 7

THE HIDDEN COSTS OF ELECTRICAL GENERATION

Today science and technology are being blamed for many of our environmental ills. It is an observable fact that plumes of smoke rising from the stacks of industrial plants have had their harmful effect upon the environment. Approximately 21.5 million tons of particulate matter alone are poured into the air of the U.S. annually from their smokestacks. The air near some of our major industrial centers is frequently unfit to breathe. Our streams have been seriously damaged resulting in elimination of much aquatic life. Perhaps the most dramatic of the aquatic catastrophes are the major fish kills. According to the U.S. Department of the Interior, over 11,750,000 fish were killed in 1969 alone by pollution from all sources.

However, to put this problem into proper perspective, we must keep in mind that science and technology are not responsible for these ills. Science and technology are neutral and merely tools for man's use. Man alone is responsible for the results of science and technology, both useful or harmful. Where there are evils, they are the evils of man, not of science. Man must make the ultimate decision concerning his environment, and he must be willing to expend efforts and money to maintain its quality. He can no longer tolerate his irresponsible behavior of the past which is resulting in the decrease in environmental quality.

The production of electrical power by any method results in hidden costs which may not be immediately evident. Nevertheless those costs are real and exact an ultimate toll. For example, electrical generating stations and their transmission lines use up valuable land areas. Fuel, whether coal, oil, or fissionable material, must be transported to these sites by some method which requires land for roadways and docking facilities. The transport vehicles also cause pollution by means of their exhausts.

Ores and fuels necessary for electrical generation must be mined. This mining also causes problems including accidental deaths of miners and diseases related to mining such as the well known *"black lung"* disease of coal miners or the lung cancer of uranium miners. Not all matter removed from mines is of value. Disposal of unwanted materials or mine wastes above ground after separation from the desired minerals has created major problems such as the culm dumps and acid mine drainage of coal-producing areas, and the piles of radioactive tailings from uranium mines in the west.

Disposal of wastes from generating stations presents another major difficulty. Conventional generating stations pour fly ash, carbon monoxide, carbon dioxide, sulfur oxides, nitrogen oxides, hydrocarbons, and measurable amounts of radioactivity into the air. Nuclear stations produce low level gaseous radioactive products which are released into the atmosphere, adding to population exposures. Spent fuel elements with their high levels of radioactivity must be processed and stored in a safe manner.

All electrical generating methods with the exception of hydro-electricity expose the public to low levels of various types of pollution. The ultimate effect of this exposure is not known at this time.

The use of our natural resources such as coal, oil, or uranium for the production of electricity depletes our limited supply of these minerals. We probably will exhaust the world's supply in the forseeable future. As the world's population grows and the standard of living rises, we must make the best use of these precious non-renewable resources.

The production of electricity has other effects. Many areas of usable land have been flooded to provide water for electrical generation. High dams have acted as barriers to fish migration. Many coastal rivers which once served as migration routes for fish such as the salmon and the shad are now completely inaccessible to those fish. Fish ladders and other artificial devices have allowed fish to migrate in other dammed streams, however, this requires additional money and effort. Thermal pollution and the addition of chemicals have seriously altered the ecological balance of many streams and many streams which once contained food fish now are fishless or contain only populations of rough fish such as the carp which can adapt to the changed aquatic environment.

Improper or unsafe use of electrical energy has also resulted in loss of life and property.

We have listed some of the detrimental effects of electrical production. There are other sources which contribute even more, such as sewage disposal, and industrial wastes. But these effects can be controlled or minimized, and the damage which has already been inflicted upon our environment can be reversed. There are cases on record where damaged natural areas have been restored. Once polluted streams support population of fish in their now clear, clean waters. Green forests stand on the sites of former strip mines. Industrial cities have cleaned up their air and water. The natural beauty of the land had been restored.

This control of pollution has one major difficulty--it is expensive. But in the long run, it is less expensive than the ruination of our natural areas. The public must be willing to bear the additional cost of maintaining and improving the quality of the environment--even at the expense of a few additional cents per kilowatt, or in the cost of a manufactured product.

CHAPTER 8

SUMMARY

A relatively inexpensive, reliable energy supply has become a necessary ingredient for the standard of living enjoyed in our nation today. Electricity has become that energy source which has met this need. It is easily transported, relatively dependable, and available at moderate prices. The utilization of this commodity has increased sharply in the past seventy years, rising from a per capita annual consumption of 50 kilowatt hours per year in 1900 to a projected per capita consumption of 33,000 kilowatt hours per year by the turn of the century. Most of the world's production and consumption of energy during its entire history has occurred during the past twenty years. Electricity lights, heats, and cools our homes, allows instant worldwide communications, powers our industrial processes, and in general frees us from the requirement for excessive manual labor for the first time in man's history. To quote S. David Freeman, former Director of the Energy Policy Staff of the President's Office of Science and Technology:

> *"After man's long struggle for bare survival and simple comforts, the stage has been reached where most people in this country are trained and paid for thinking. An abundant supply of low-cost energy is essential to continue this trend, freeing man from burdensome chores and enabling him to spend more and more of his time enjoying the pleasures of affluence, leisure, and education. It is for these reasons that national policy has long been to assure an abundant supply of low cost energy".*

But we must keep before us the fact that all energy sources have some impact upon the environment, and we must be prepared to make several vital decisions in the near future:

1. Is it possible to produce electrical energy to meet the increasing

needs and still maintain a quality environment?

2. What energy source or combination of energy sources will produce the least detrimental effects upon the environment?

These are decisions which the American public must make. They are extremely important decisions which will affect the lives of unborn generations. We must balance the availability and importance of fuels, the impact on the environment, and man's needs. We must keep in mind that pollution is more a byproduct of affluence than of poverty.

Whether the production of energy will come from fossil fuels, nuclear reactors, or from a variety of sources is a decision which must be made after a careful weighing of the facts. In the words of Congressman Craig Hosmer of the Joint Committee on Atomic Energy:

> *"Society must balance risk against potential benefits to the people; the ultimate decision should be that which is the greatest good for the greatest number."*

The decision is yours.

Appendix I - Alternatives to Nuclear Power

Fossil Fuels

Mineable coal reserves are esitmated to be adequate for several centuries, and will continue to be used for power production. But some way must be found to remove the sulfur and fly ash from the stack releases. Strip mining is the cheapest way to extract coal, but due to its devastation of the countryside this method may be outlawed, placing more emphasis upon expensive, and more dangerous deep mining procedures. This will take a toll of human lives. Over 80,000 miners have died in deep mining accidents since 1910.

Oil and natural gas supplies will be depleted in less than a century. But before this happens oil and natural gas may have to be rationed as a source of raw materials for manufactured products such as plastics, drugs, and even artificial protein.

Solar Energy

Solar cells currently are about 10 per cent efficient. For a 1000 megawatt solar plant we would need banks of solar cells covering an area of nearly 9 square miles. We simply do not have the land area for enough solar plants to fill our energy needs using our present technology.

Water Power

Hydroelectric power today accounts for about four per cent of present electrical production. However, most of the suitable dam sites already have been exploited. Most new sites are in remote areas and would require industrialization of these areas at considerable expense.

Geothermal Energy

Power plants using steam from wells drilled in volcanic areas have been in operation in Italy since 1904. The first geothermal plant in the United States began operation in 1960 at The Geysors in California. Its present capacity is about 300 megawatts.

From a study of the world's geothermal areas it has been estimated that the world may ultimately extract about 60,000 megawatts of power from this source, and the life expectancy of geothermal plants is only about 50 years.

Tidal Power

Tidal power plants would use the power of the tides, which reverse their direction of flow four times per day as tidal basins are alternately filled and emptied. Tidal power plants are possible only in a few favorable localities around the world where a large tidal flow exists and there is a bay or estuary capable of being enclosed by dams. This would supply only a small fraction of the world's power needs.

Fusion

Fusion power, if achieved, will be the answer to our search for a clean, universally available power supply which will last into future centuries. But controlled fusion has not yet been achieved, and may take years to be developed.

The fusion reaction will use the heavy isotope of hydrogen called deuterium. Deuterium can be economically separated from sea water, which covers 2/3 of the surface of the earth, giving us an almost inexhaustable supply, many thousands of times the energy equivalent of the world's coal supply.

But the production of electrical energy from controlled fusion - if it ever comes - is in the future. Research must go on, but in the meantime we must have a source of electrical energy.

APPENDIX II

GLOSSARY OF TERMS

The following terms are included to aid you in your understanding of the textual material included here, and the terms which you will encounter as you investigate the effects of power generation. Many of the Nuclear terms are excerpted from the U.S. Atomic Energy Commission booklet *Nuclear Terms: A Brief Glossary*. Many other terms have been added to this by the committee in order to increase your understanding of the specific words relating to power production.

absorbed dose	When ionizing radiation passes through matter, some of its energy is imparted to the matter. The amount absorbed per unit mass of irradiated material is called the absorbed dose, and is measured in rems and rads.
absorber	Any material that absorbs or diminishes the intensity of ionizing RADIATION. Neutron absorbers, like boron, hafnium, and cadmium, are used in control rods for reactors. Concrete and steel absorb gamma rays and neutrons in reactor shields. A thin sheet of paper or metal will abosrb or attenuate alpha particles and all except the most energetic beta particles.
absorption	The process by which the number of particles of photons entering a body of MATTER is reduced by interaction of the particles or radiation with the matter; similarly, the reduction of the energy of a particle while traversing a body of matter.
activiation	The process of making a material radioactive by bombardment with neutrons, protons, or other nuclear particles.
AEJ	The U.S. Atomic Energy Commission.
air sampling	The collection and analysis of samples of air to measure its radioactivity or to detect the presence of radioactive substance.

alpha particle	(Symbol) A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together, hence is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of radiation.
atom	A particle of matter indivisible by chemical means. It is the fundamental building block of the chemical elements.
atomic bomb	A bomb whose energy comes from the fission of heavy elements such as uranium or plutonium.
Atomic Energy Commission	(Abbreviation AEC) The independent civilian agency of the federal government with statutory responsibility for atomic energy matters. Also the body of five persons, appointed by the President, to direct the agency.
atomoc mass	(See atomic weight, mass.)
Atomic mass unit	(Symbol amu) One-twelfth the mass of a neutral atom of the most abundant isotope of ^{12}C.
atomic number	(Symbol Z) The number of protons in the nucleus of an atom, and also its positive charge. Each chemical element has its characteristic atomic number, and the atomic numbers of the known elements form a complete series from 1 (hydrogen) to 103 (lawrencium.)
atomic reactor	A nuclear reactor.
atomic weight	The mass of an atom relative to other atoms. The present-day basis of the scale of atomic weights is carbon; the commonest isotope of this element has arbitrarily been assigned an atomic weight of 12. The unit of the scale is 1/12 the weight of the carbon-12 atom, or roughly the mass of one proton or one neutron. The atomic weight of any element is approximately equal to the total number of protons and neutrons in its nucleus.
autoradiograph	A photographic record of radiation from radioactive material in an object, made by placing the object very close to a photographic film or emulsion. The process is called autoradiography. It is used, for instance, to locate radioactive atoms or tracers in metallic or biological samples.

background radiation	The radiation in man's natural environment, including cosmic rays and radiation from the naturally radioactive elements, both outside and inside the bodies of men and animals. It is also called natural radiation. The term may also mean radiation. The term may also mean radiation that is unrelated to a specific experiment.
backscatter	When radiation of any kind strikes matter (gas, liquid or solid), some of it may be reflected or scattered back in the general direction of the source. An understanding or exact measurement of the amount of backscatter is important when beta particles are being counted in an ionization chamber, in medical treatment with radiation, or in use of industrial radioisotopic thickness gauges.
barrier shield	A wall or enclosure shielding the operator from an area where radioactive material is being used or processed by remote control equipment.
beta particle	(Symbol B-) An elementary particle emitted from a nucleus during radioactive decay, with a single electrical charge and a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron. Beta radiation may cause skin burns, and beta-emitters are harmful if they enter the body. Beta particles are easily stopped by a thin sheet of metal.
Bev	Symbol for billion (or 10^9) electron volts. Also written as BeV. (See electron volt.)
binding energy	The binding energy of a nucleus is the minimum energy required to dissociate it into its component neutrons and protons.
biological dose	The radiation dose absorbed in biological material. Measured in rems.
biological half-life	The time required for a biological system, such as a man or an animal, to eliminate, by natural processes, half the amount of substance (such as a radioactive material) that has entered it.
biological shield	A mass of absorbing material placed around a reactor or radioactive source to reduce the radiation to a level that is safe for human beings.

body burden	The amount of radioactive material present in the body of a man or an animal.
boiling water reactor	A reactor in which water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam can be used directly to drive a turbine.
bone seeker	A radioisotope that tends to accumulate in the bones when it is introduced into the body. An example is strontium-90, which behaves chemically like calcium.
breeder reactor	A reactor that produces fissionable fuel as well as consuming it, especially one that creates more than it consumes. The new fissionable material is created by capture in fertile materials of neutrons from fission. The process by which this occurs is known as breeding.
by-product material	Any radioactive material (except source material or fissionable material) obtained during the production or use of source material or fissionable material. It includes fission products and many other radioisotopes produced in nuclear reactors.
cathode rays	A stream of electrons emitted by the cathode, or negative electrode, of a gas-discharge tube or by a hot filament in a vacuum tube, such as a television tube.
chain reaction	A reaction that stimulates its own repetition. In a fission chain reaction a fissionable nucleus absorbs a neutron and fissions, releasing additional neutrons. These in turn can be absorbed by other fissionable nuclei, releasing still more neutrons. A fission chain reaction is self-sustaining when the number of neutrons released in a given time equals or exceeds the number of neutrons lost by absorption in non-fissioning material or by escape from the system.
charged particle	An ion; an elementary particle that carries a positive or negative electric charge.
chromosome	The determiner of heredity within a cell.
closed-cycle reactor system	A reactor design in which the primary heat of fission is transferred outside the reactor core to do useful work by means of a coolant circulating in a completely closed system that includes a heat exchanger.

coffin	A heavily shielded shipping cask for spent (used) fuel elements. Some coffins weight as much as 75 tons.
Compton effect	Elastic scattering of photons (x-rays or gamma rays) by electrons. In each such process the electron gains energy and recoils, and the photon loses energy. This is one of three ways photons lose energy upon interacting with matter, and is the usual method with photons of intermediate energy and materials of low atomic number. It is named for A. H. Compton, American physicist, who discovered it in 1923.
containment	The provision of a gas tight shell or other enclosure around a reactor to confine fission products that otherwise might be released to the atmosphere in the event of an accident.
containment vessel	A gas tight shell or other enclosure around a reactor.
control rod	A rod, plate, or tube containing a material that readily absorbs neutrons (hafnium, boron, etc.) used to control the power of a nuclear reactor. By absorbing neutrons, a control rod prevents the neutrons from causing further fission.
coolant	A substance circulated through a nuclear reactor to remove or transfer heat. Common coolants are water, air, carbon dioxide, liquid sodium and sodium-potassium alloy.
cooling tower	A tower designed to aid in the cooling of water after it leaves the turbines of a power plant before it is recycled.
core	The central portion of a nuclear reactor containing the fuel elements and usually the moderator, but not the reflector.
counter	A general designation applied to radiation detection instruments or survey meters that detect and measure radiation.
critical mass	The smallest mass of fissionable material that will support a self-sustaining chain reaction under stated conditions.
criticality	The state of a nuclear reactor when it is sustaining a chain reaction.

curie	(Symbol c) The basic unit to describe the intensity of radioactivity in a sample of material. The curie is equal to 37 billion disintegrations per second, which is approximately the rate of decay of 1 gram of radium. A curie is also a quantity of any nuclide having 1 curie of radioactivity. Named by Marie and Pierre Curie, who discovered radium in 1898.
daughter	A nuclide formed by the radioactive decay of another nuclide, which in this context is called the parent. (See radioactive series.)
decay chain	A radioactive series.
decay heat	The heat produced by the decay of radioactive nuclides.
decay, radioactive	The spontaneous transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide. The process results in a decrease, with time, of the number of the original radioactive atoms in a sample. It involves the emission from the nucleus of alpha particles, beta particles (or electrons), or gamma rays; or the nuclear capture or ejection of orbital electrons; or fission. Also called radioactive disintegration.
decontamination	The removal of radioactive contaminants from surfaces or equipment, as by cleaning and washing with chemicals.
detector	Material or a device that is sensitive to radiation and can produce a response signal suitable for measurement or analysis. A radiation detection instrument.
deuterium	(Symbol ^{2}H or D) An isotope of hydorgen whose nucleus contains one neutron and one proton and is therefore about twice as heavy as the nucleus of normal hydrogen, which is only a single proton. Deuterium is often referred to as heavy hydrogen; it occurs in nature as 1 atom to 6500 atoms of normal hydrogen. It is nonradioactive. (See heavy water).
deutron	The nucleus of deuterium. It contains one proton and one neutron.
dose	(See absorbed dose, biological dose, maximum permissible dose, threshold dose.)

dose equivalent	A term used to express the amount of effective radiation when modifying factors have been considered. The product of absorbed dose multiplied by a quality factor multiplied by a distribution factor. It is expressed numerically in rems.
dose rate	The radiation dose delivered per unit time and measured, for instance, in rems per hour.
dosimeter	A device that measures radiation dose, such as a film badge or ionization chamber.
doubling dose	Radiation dose which would eventually cause a doubling of gene mutations.
electron	(symbol e^-) An elementary particle with a unit negative electrical charge and a mass 1/1837 that of the proton. Electrons surround the positively charged NUCLEI and determine the chemical properties of the atom. Positive electrons, or positrons, also exist.
electron volt	(Abbreviation ev or eV) The amount of kinetic energy gained by an electron when it is accelerated through an electric potential difference of 1 volt. It is equivalent to 1.603×10^{-12} erg. It is a unit of energy, or work, not of voltage.
element	One of the 103 known chemical substances that cannot be divided into simpler substances by chemical means. A substance whose atoms all have the same atomic number. Examples: hydrogen, lead, uranium. (Not to be confused with fuel element.)
exclusion area	An area immediately surrounding a nuclear reactor where human habitation is prohibited to assure safety in the event of accident.
excursion	A sudden, very rapid rise in the power level of a reactor caused by supercriticality. Excursions are usually quickly suppressed by the negative temperature coefficient of the reactor and/or by automatic control rods.
fast breeder reactor	A reactor that operates with fast neutrons and produces more fissionable material than it consumes.
fast neutron	A neutron with energy greater than approximately 100,000 electron volts.

fast reactor	A reactor in which the fission chain reaction is sustained primarily by fast neutrons rather than by thermal or intermediate neutrons. Fast reactors contain little or no moderator to slow down the neutrons from the speeds at which they are ejected from fissioning nuclei.
fertile material	A material, not itself fissionable by thermal neutrons, which can be converted into a fissile material by irradiation in a reactor. There are two basic fertile materials, Uranium-238 and Thorium-232. When these fertile materials capture neutrons, they are partially converted into fissile Plutonium-239 and Uranium-233, respectively.
film badge	A light-tight package of photographic film worn like a badge by workers in nuclear industry or research, used to measure possible exposure to IONIZING RADIATION. The absorbed dose can be calculated by the degree of film darkening caused by the irradiation.
fissile material	While sometimes used as a synonym for fissionable material, this term has also acquired a more restricted meaning, namely, any material fissionable by neutrons of all energies, including (and especially) thermal (slow) neutrons as well as fast neutrons; for example, Uranium-235 and Plutonium-239.
fission	The splitting of a heavy nucleus into two approximately equal parts (which are nuclei of lighter elements), accompanied by the release of a relatively large amount of energy and generally one or more neutrons. Fission can occur spontaneously, but usually is caused by nuclear absorption of gamma rays, neutrons or other particles.
fission fragments	The two nuclei which are formed by the fission of a nucleus. Also referred to as primary fission products. They are of medium atomic weight, and are radioactive.
fission products	The nuclei (fission fragments) formed by the fission of heavy elements, plus the nuclides formed by the fission fragments' radioactive decay.
fissionable material	Commonly used as a synonym for fissile material. The meaning of this term also has been extended to include material that can be fissioned by fast neutrons only, such as Uranium-238. Used in reactor operations to mean fuel.

flux (neutron)	A measure of the intensity of neutron radiation. It is the number of neutrons passing through 1 square centimeter of a given target in 1 second. Expressed as nv, where n = the number of neutrons per cubic centimeter and v = their velocity in centimeters per second.
food chain	The pathways by which any material (such as radioactive material from fallout) passes from the first absorbing organism through plants and animals to man.
fuel	Fissionable material used or usable to produce energy in a reactor. Also applied to a mixture, such as natural uranium, in which only part of the atoms are readily fissionable, if the mixture can be made to sustain a chain reaction.
fuel cycle	The series of steps involved in supplying fuel for nuclear power reactors. It includes mining, refining, the original fabrication of fuel elements, their use in a reactor, chemical processing to recover the fissionable material remaining in the spent fuel, reenrichment of the fuel material, and refabrication into new fuel elements.
fuel element	A rod, tube, plate, or other mechanical shape or form into which nuclear fuel is fabricated for use in a reactor. (Not to be confused with element).
fuel reprocessing	The processing of reactor fuel to recover the unused fissionable material.
fusion	The formation of a heavier nucleus from two lighter ones (such as hydrogen isotopes), with the attendant release of energy (as in a hydrogen bomb).
gamma rays	(Symbol) High-energy, short-wave length electromagnetic radiation. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded against by dense materials, such as lead or depleted uranium. Gamma rays are essentially similar to X-rays, but are usually more energetic, and are nuclear in origin.
gas-cooled reactor	A nuclear reactor in which a gas is the coolant.
gaseous diffusion (plant)	A method of isotopic separation based on the fact that gas atoms or molecules with different masses will diffuse through a porous barrier (or membrane) at different rates. The method is used by the AEC

	to separate Uranium-235 from Uranium-238; it requires large gaseous-diffusion plants and enormous amounts of electric power.
Geiger-Muller counter (Geiger-Muller tube)	A radiation detection and measuring instrument. It consists of gas-filled (Geiger-Muller) tube containing electrodes, between which there is an electrical voltage but no current flowing. When ionizing radiation passes through the tube, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of radiation. It is also often known as Geiger counter; it was named for Hans Geiger and W. Muller who invented it in the 1920s.
genetic effects of radiation	Radiation effects that can be transferred from parent to offspring. Any radiation-caused changes in the genetic material of sex cells.
graphite	A very pure form of carbon used as a moderator in nuclear reactors.
half-life	The time in which half the atoms of particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years.(See decay, radioactive.)
half-life, biological	(See biological half-life.)
half-life, effective	The time required for a radionuclide contained in a biological system, such as a man or an animal, to reduce its activity by half as a combined result of radioactive decay and biological elimination. (Compare biological half-life; see half-life.)
half-thickness	The thickness of any given absorber that will reduce the intensity of a beam of radiation to one-half its initial value.
health physics	The science concerned with recognition, evaluation, and control of health hazards from ionizing radiation.
heat exchanger	Any device that transfers heat from one fluid (liquid or gas) to another or to the environment.
heat sink	Anything that absorbs heat; usually part of the environment, such as the air, a river, or outer space.

heavy water	(Symbol D_2O) Water containing significantly more than the natural proportion (one in 6500) of heavy hydrogen (deuterium) atoms to ordinary hydrogen atoms. Heavy water is used as a moderator in some reactors because it slows down neutrons effectively and also has a low cross section for absorption of neutrons.
heavy-water moderated reactor	A reactor that uses heavy water as its moderator. Heavy water is an excellent moderator and thus permits the use of inexpensive natural (unenriched) uranium as a fuel.
hot	Highly radioactive.
induced radioactivity	Radioactivity that is created when substances are bombarded with neutrons, as from a nuclear explosion or in a reactor, or with charged particles produced by accelerators.
intensity	The energy or the number of photons or particles of any radiation incident upon a unit area or flowing through a unit of solid material per unit of time. In connection with radioactivity, the number of atoms disintegrating per unit of time.
ion	An atom or molecule that has lost or gained one or more electrons. By this ionization it becomes electrically charged. Examples: an alpha particle, which is a helium atom minus two electrons; a proton, which is a hydrogen atom minus its electron.
ionization	The process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or nuclear radiations can cause ionization.
ionization chamber	An instrument that detects and measures ionizing radiation by measuring the electrical current that flows when radiation ionizes gas in a chamber, making the gas a conductor of the electricity.
ionizing event	Any occurence in which an ion or group of ions is produced; for example, by passage of a charged particle through matter.
ionizing radiation	Any radiation displacing electrons from atoms or mulecules, thereby producing ions. Examples: alpha, beta, gamma radiation, short-wave ultraviolet light. Ionizing radiation may produce severe skin or tissue damage.

irradiation	Exposure to radiation, as in a nuclear reactor.
isotope	One of two or more atoms with the same atomic number (the same chemical element) but with different atomic weights. An equivalent statement is that the nuclei of isotopes have the same number of prontons, but different numbers of neutrons. Thus, $^{12}_{6}C$, $^{13}_{6}C$, and ^{14}C are isotopes of the element carbon, the subscripts denoting their common atomic numbers, the superscripts denoting the differing mass numbers, or approximate atomic weights. Isotopes usually have very nearly the same chemical properties, but somewhat different physical properties.
isotope separation	The process of separating isotopes from one another, or changing their relative abundances, as by gaseous diffusion or electromagnetic separation. All systems are based on the mass differences of the isotopes. Isotope separation is a step in the isotopic enrichment process.
kilo	A prefix that multiplies a basic unit by 1000.
lethal dose	A dose of ionizing radiation sufficient to cause death. Median lethal dose (MLD or LD-50) is the dose required to kill within a specified period of time (usually 30 days) half of the individuals in a large group of organisms similarly exposed. The LD-50/30 for man is about 400-450 roentgens.
low population zone	An area of low population density sometimes required around a nuclear installation. The number and density of residents is of concern in providing, with reasonable probability, that effective protection measures can be taken if a serious accident should occur.
magnetic bottle	A magnetic field used to confine or contain a plasma in controlled fusion (thermonuclear) experiments.
magnetic mirror	A magnetic field used in controlled fusion experiments to reflect charged particles back into the central region of a magnet bottle.
mass	The quantity of matter in a body. Often used as a synonym for weight, which, strictly speaking, is the force exerted by a body under the influence of gravity.

mass-energy equation (mass-energy equivalence) (mass-energy relation)	The statement developed by Albert Einstein, German-born American physicist, that *"the mass of a body is a measure of its energy content,"* as an extension of his 1905 Special Theory of Relativity. The statement was subsequently verified experimentally by measurements of mass and energy in nuclear reactions. The equation, usually given as: $^2E = mc$, shows that when the energy of a body changes by an amount, E, (no matter what form the energy takes) the mass, m, of the body will change by an amount equal to E/c^2. (The factor c^2, the square of the speed of light in a vacuum, may be regarded as the conversion factor relating units of mass and energy.) The equation predicted the possibility of releasing enormous amounts of energy (in the atomic bomb) by the conversion of mass to energy. It is also called the Einstein equation.
matter	The substance of which a physical object is composed. All materials in the universe have the same inner nature, that is, they are composed of atoms, arranged in different (and often complex) ways; the specific atoms and the specific arrangements identify the various materials.
maximum credible accident	The most serious reactor accident that can reasonably be imagined from any adverse combination of equipment malfunction, operating errors, and other foreseeable causes, the term is used to analyze the safety characteristics of a reactor. Reactors are designed to be safe even if a maximum credible accident should occur.
maximum permissible concentration (MPC)	The amount of radioactive material in air, water or food which might be expected to result in a maximum permissible dose to persons consuming ghem at a standard rate of intake. An obsolescent term.
maximum permissible dose (MPD) (maximum permissible exposure)	That dose of ionizing radiation established by compentent authorities as an amount below which there is no reasonable expectation of risk to human health, and which at the same time is somewhat below the lowest level at which a definite hazard is believed to exist. An obsolescnet term.
mean life	The average time during which an atom, an excited nucleus, a radionuclide or a particle exists in a particular form.
median lethal dose	(See lethal dose.)

Mev	One million (or 10^6) electron volts. (Also written as MeV.)
moderator	A material, such as ordinary water, heavy water, or graphite, used in a reactor to slow down high-velocity neutrons, thus increasing the likelihood of further fission.
molecule	A group of atoms held together by chemical forces. The atoms in the molecule may be identical, as in H_2, S_2, and S_8, or different, as in H_2O and CO_2. A molecule is the smallest unit of matter which can exist by itself and retain all its chemical properties. (Compare atom, ion.)
mutation	A permanent transmissible change in the characteristics of an offspring from those of its parents.
natural radiation natural radioactivity	Background radiation.
natural uranium	Uranium as found in nature, contains 0.7 per cent of ^{235}U, 99.3 per cent of ^{238}U, and a trace of ^{234}U. It is also called normal uranium.
neutron	(Symbol n) An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen. A free neutron is unstable and decays with a half-life of about 13 minutes into an electron, proton, and neutrino. Neutrons sustain the fission chain reaction in a nuclear reactor,
neutron capture	The process in which an atomic nucleus absorbs or captures a neutron.
neutron density	The number of neutrons per cubic centimeter in the core of a reactor.
nuclear energy	The energy liberated by a nuclear reaction (fission or fusion) or by radioactive decay.
nuclear power plant	Any device, machine, or assembly that converts nuclear energy into some form of useful power, such as mechanical or electrical power. In a nuclear electric power plant, heat produced by a reactor is generally used to make steam to drive a turbine that in turn drives an electric generator.
nuclear reaction	A reaction involving a change in an atomic nucleus, such as fission, fusion, neutron capture, or radioactive decay, as distinct from a chemical reaction, which is limited to changes in the electron structure surrounding the nucleus.

nuclear reactor	A device in which a fission chain reaction can be initiated, maintained, and controlled. Its essential component is a core with fissionable fuel. It usually has a moderator, a reflector, shielding, coolant, and control mechanisms. Sometimes called an atomic *"furnace"* it is the basic machine of nuclear energy.
nuclear superheating	Superheating the steam produced in a reactor by using additional heat from a reactor. Two methods are commonly employed: recirculating the steam through the same core in which it is first produced (integral superheating) or passing the steam through a second and separate reactor.
nucleon	A constituent of an atomic nucleus, that is, a proton or a neutron.
nucleonics	The science and technology of nuclear energy and its applications.
nucleus	The small, positively charged core of an atom. It is only about 1/10,000 the diameter of the atom but contains nearly all the atom's mass. All nuclei contain both protons and neutrons, except the nucleus of ordinary hydrogen, which consists of a single proton.
nuclide	A general term applicable to all atomic forms of the elements. The term is often erroneously used as a synonym for *"isotope"*, which properly has a more limited definition. Whereas isotopes are the various forms of a single element (hence are a family of nuclides) and all have the same atomic number and number of protons, nuclides comprise all the isotopic forms of all the elements. Nuclides are distinguished by their atomic number, atomic mass, and energy state.
parent	A radionuclide that upon radioactive decay or disintegration yields a specific nuclide (the daughter), either directly or as a later member of a radioactive series.
permissible dose	(See maximum permissible dose.)
personnel monitoring	Determination by either physical or biological measurement of the amount of ionizing radiation to which an individual has been exposed, such as by measuring the darkening of a film badge or performing a radon breath analysis.

phantom	A volume of material approximating as closely as possible the density and effective atomic number of living tissue, used in biological experiments involving radiation.
pig	A heavy shielded container (usually lead) used to ship or store radioactive materials.
pile	Old term for nuclear reactor. This name was used because the first reactor was built by piling up graphite blocks and natural uranium.
pinch effect	In controlled fusion experiments, the effect obtained when an electric current, flowing through a column of plasma, produces a magnetic field that confines and compresses the plasma.
plasma	An electrically neutral gaseous mixture of positive and negative ions. Sometimes called the *"fourth state of matter"*, since it behaves differently from solids, liquids and gases. High-temperature plasmas are used in controlled fusion experiments.
Plowshare	The Atomic Energy Commission program of research and development on peaceful uses of nuclear explosives. The possible uses include large-scale excavation, such as for canals and harbors, crushing ore bodies, and producing heavy transuranic isotopes. The term is based on a Biblical reference: Isaiah 2:4.
plutonium	(Symbol Pu) A heavy, radioactive, man-made, metalic element with atomic number 94. Its most important isotope is fissionable Plutonium-239, produced by neutron irradiation of Uranium-238. It is used for reactor fuel and in weapons.
pool reactor	A reactor in which the fuel elements are suspended in a pool of water that serves as the reflector, moderator, and coolant. Popularly called a swimming pool reactor, it is usually used for research and training.
power reactor	A reactor designed to produce useful nuclear power, as distinguished from reactors used primarily for research or for producing radiation or fissionable materials.
pressure vessel	A strong-walled container housing the core of most types of power reactors; it usually also contains moderator, reflector, thermal shield, and control rods.

pressurized water reactor	A power reactor in which heat is transferred from the core to a heat exchanger by water kept under high pressure to achieve high temperature without boiling in the primary system. Steam is generated in a secondary circuit. Many reactors producing electric power are pressurized water reactors.
primary fission products	Fission fragments.
protection	Provisions to reduce exposure of persons to radiation. For Example, protective barriers to reduce external radiation or measures to prevent inhalation of radioactive materials.
rad	(acronym for radiation absorbed dose.) The basic unit of absorbed dose of ionizing radiation. A dose of one rad means the absorption of 100 ergs of radiation energy per gram of absorbing material.
radiation	The emission and propagation of energy through matter or space by means of electromagnetic disturbances which display both wave-like and particle-like behavior; in this context the *particles"* are known as photons. Also, the energy so propagated. The term has been extended to include streams of fast-moving particles (alpha and beta particles, free neutrons, cosmic radiation, etc.) Nuclear radiation is that emitted from atomic nuclei in various nuclear reactions, including alpha, beta and gamma radiation and neutrons.
radiation area	Any accessible area in which the level of radiation is such that a major portion of an individual's body could receive in any one hour a dose in excess of 5 millirem, or in any five consecutive days a dose in excess of 150 millirem.
radiation burn	Radiation damage to the skin. Beta burns result from skin contact with or exposure to emitters of beta particles. Flash burns result from sudden thermal radiation.
radiation damage	A general term for the harmful effects of radiation on matter.
radiation detection instruments	Devices that detect and record the characteristics of ionizing radiation.
radiation dosimetry	The measurement of the amount of radiation delivered to a specific place or the amount of radiation that was abosrbed there.

radiation illness	An acute organic disorder that follows exposure to relatively severe doses of ionizing radiation. It is characterized by nausea, vomiting, diarrhea, blood cell changes, and in later stages by hemorrhage and loss of hair.
radiation monitoring	Continuous or periodic determination of the amount of radiation present in a given area.
radiation protection	Legislation and regulations to protect the public and laboratory or industrial workers against radiation. Also measures to reduce exposure to radiation.
radiation protection guide	The officially determined radiation doses which should not be exceeded without careful consideration of the reasons for doing so. These standards, established by the Federal Radiation Council, are equivalent to what was formerly called the maximum permissible dose or maximum permissible exposure.
radiation shielding	Reduction of radiation by interposing a shield of absorbing material between any radioactive source and a person, laboratory area, or radiation-sensitive device.
radiation source	Usually a man-made, sealed source of radioactivity used in teletherapy, radiography, as a power source for batteries, or in various types of industrial gauges. Machines such as accelerators, and radioisotopic generators and natural radionuclides may also be considered as sources.
radiation standards	Exposure standards, permissible concentrations, rules for safe handling, regulations for transportation, regulations for industrial control of radiation, and control of radiation exposure by legislative means. (See radiation protection, radiation protection guide.)
radiation sterilization	Use of radiation to cause a plant or animal to become sterile, that is, incapable of reproduction. Also the use of radiation to kill all forms of life (especially bacteria) in food, surgical sutures, etc.
radiation warning symbol	An officially prescribed symbol (a magenta trefoil on a yellow background) which should always be displayed when a radiation hazard exists.
radioactive	Exhibiting radioactivity or pertaining to radioactivity.

radioactive contamination	Deposition of radioactive material in any place where it may harm persons, spoil experiments, or make products or equipment unsuitable or unsafe for some specific use. The presence of unwanted radioactive matter. Also radioactive material found on the walls of vessels in used-fuel processing plants, or radioactive material that has leaked into a reactor coolant. Often referred to only as contamination.
radioactive dating	A technique for measuring the age of an object or sample of material by determining the ratios of various radioisotopes or products of radioactive decay it contains. For example, the ratio of Carbon-14 to Carbon-12 reveals the approximate age of bones, pieces of wood, or other archeological specimens that contain carbon extracted from the air at the time of their origin.
radioactive isotope	A radioisotope.
radioactive series	A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nuclide results. The first member is called the parent, the intermediate members are called daughters, and the final stable member is called the end product.
radioactive waste	(See waste, radioactive.)
radioactivity	The spontaneous decay or disintegration of an unstable atomic nucleus, usually accompanied by the emission of ionizing radiation. (Often shortened to *"activity".)*
radioecology	The body of knowledge and the study of the effects of radiation on species of plants and animals in natural communities.
radioisotope	A radioactive isotope. An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation. More than 1300 natural and artificial radioisotopes have been identified.
radioisotopic generator	A small power generator that converts the heat released during radioactive decay directly into electricity. These generators generally produce only a few watts of electricity and use thermoelectric or thermionic converters. Some also function as electrostatic converters to produce a small voltage. Sometimes called an *"atomic battery"*.

radiology	The science which deals with the use of all forms of ionizing radiation in the diagnosis and the treatment of disease.
radiomutation	A permanent, transmissible change in form, quality, or other characteristic of a cell or offspring from the characteristics of its parent, due to radiation exposure. (See genetic effects of radiation, mutation.)
radioresistance	A relative resistance of cells, tissues, organs, or organisms to the injurious action of radiation. (Compare radiosensitivity.)
radiosensitivity	A relative susceptibility of cells, tissues, organs or organisms to the injurious action of radiation. (Compare radioresistance.)
radium	(Symbol Ra) A radioactive metallic element with atomic number 88. As found in nature, the most common isotope has an atomic weight of 226. It occurs in minute quantities associated with uranium in pitchblende, carnotite and other minerals.
radon	Symbol Rn) A radioactive element, one of the heaviest gases known. Its atomic number is 86, and its atomic weight is 222. It is a daughter of radium in the uranium radioactive series.
reactor	(See nuclear reactor.)
recycling	The reuse of fissionable material, after it has been recovered by chemical processing from spent or depleted reactor fuel, reenriched, and then refabricated into new fuel elements.
reflector	A layer of material immediately surrounding a reactor core which scatters back or reflects into the core many neutrons that would otherwise escape. The returned neutrons can then cause more fissions and improve the neutron economy of the reactor. Common reflector materials are graphite, beryllium and natural uranium.
regulating rod	A reactor control rod used for making frequent fine adjustments in reactivity.
relative biological effectiveness (RBE)	A factor used to compare the biological effectiveness of different types of ionizing radiation. It is the inverse ratio of the amount of absorbed radiation, required to produce a given effect, to a standard (or reference) radiation required to produce the same effect.

rem	(Acronym for roentgen equivalent man.) The unit of dose of any ionizing radiation which produces the same biological effect as a unit of absorbed dose of ordinary X-rays. The RBE dose (in rems) = RBE x absorbed dose (in rads).
rep	(Acronym for roentgen equivalent physical.) An obsolete unit of absorbed dose of any ionizing radiation, with a magnitude of 93 ergs per gram. It has been superseded by the rad.
reprocessing	fuel reprocessing
roentgen	(Abbreviation r) A unit of exposure to ionizing radiation. It is that amount of gamma or X-rays required to produce ions carrying 1 electrostatic unit of electrical charge (either positive or negative) in 1 cubic centimeter of dry air under standard conditions. Named after Wilhelm Roentgen, German scientist who discovered X-rays in 1895.
roentgen equivalent, man	(See rem.)
roentgen rays	X-rays.
safety rod	A standby control rod used to shut down a nuclear reactor rapidly in emergencies.
scaler	An electronic instrument for rapid counting of radiation-induced pulses from Geiger counters or other radiation detectors. It permits rapid counting by reducing (by a definite scaling factor) the number of pulses entering the counter.
scram	The sudden shutdown of a nuclear reactor, usually by rapid insertion of the safety rods. Emergencies or deviations from normal reactor operation cause the reactor operator or automatic control equipment to scram the reactor.
shield (shielding)	A body of material used to reduce the passage of radiation.
somatic effects of radiation	Effects of radiation limited to the exposed individual, as distinguished from genetic effects (which also affect subsequent, unexposed generations). Large radiation doses can be fatal. Smaller doses may make the individual noticeably ill, may merely produce temporary changes in blood-cell levels detectable only in the laboratory, or may produce no detectable effects whatever. Also called physiological effects of radiation. (Compare genetic effects of radiation.)

spent (depleted) fuel	Nuclear reactor fuel that has been irradiated (used) to the extent that it can no longer effectively sustain a chain reaction.
spill	The accidental release of radioactive material.
stable	Incapable of spontaneous change. Not radioactive.
stable isotope	An isotope that does not undergo radioactive decay.
subcritical assembly	A reactor consisting of a mass of fissionable material and moderator whose effective multiplication factor is less than one and that hence cannot sustain a chain reaction. Used primarily for educational purposes.
subcritical mass	An amount of fissionable material insufficient in quantity or of improper geometry to sustain a fission chain reaction.
supercritical reactor	A reactor in which the effective multiplication factor is greater than one; consequently a reactor that is increasing its power level. If uncontrolled, a supercritical reactor would undergo an excursion.
superheating	The heating of a vapor, particularly saturated (wet) steam, to a temperature much higher than the boiling point at the existing pressure. This is done in power plants to improve efficiency and to reduce condensation in the turbines.
survey meter	Any portable radiation detection instrument especially adapted for surveying or inspecting an area to establish the existence and amount of radioactive material present.
thermal breeder reactor	A breeder reactor in which the fission chain reaction is sustained by thermal neutrons.
thermal (slow) neutron	A neutron in thermal equilibrium with its surrounding medium. Thermal neutrons are those that have been slowed down by a moderator to an average speed of about 2200 meters per second (at room temperature) from the much higher initial speeds they had when expelled by fission. This velocity is similar to that of gas molecules at ordinary temperatures.
thermal reactor	A reactor in which the fission chain reaction is sustained primarily by thermal neutrons. Most reactors are thermal reactors.

thermal shield	A layer or layers of high density material located within a reactor pressure vessel or between the vessel and the biological shield to reduce radiation heating in the vessel and the biological shield.
thermonuclear reaction	A reaction in which very high temperatures bring about the fusion of two light nuclei to form the nucleus of a heavier atom, releasing a large amount of energy. In a hydrogen bomb, the high temperature to initiate the thermonuclear reaction is produced by a preliminary fission reaction.
threshold dose	The minimum dose of radiation that will produce a detectable biological effect.
tracer, isotopic	An isotope of an element, a small amount of which may be incorporated into a sample of material (the carrier) in order to follow (trace) the course of that element through a chemical, biological or physical process, and thus also follow the larger sample. The tracer may be radioactive, in which case observations are made by measuring the radioactivity. If the tracer is stable, mass spectrometers, density measurement, or neutron activation analysis may be employed to determine isotopic composition. Tracers also are called labels or tags, and materials are said to be labeled or tagged when radioactive tracers are incorporated in them.
unstable isotope	A radioisotope.
uranium	(Symbol U) A radioactive element with the atomic number 92 and, as found in natural ores, an average atomic weight of approximately 238. The two principal natural isotopes are Uranium-235 (0.7 per cent of natural uranium), which is fissionable, and Uranium-238 (99.3 per cent of natural uranium) which is fertile. Natural uranium also includes a minute amount of Uranium-234. Uranium is the basic raw material of nuclear energy.
uranium enrichment	(See isotopic enrichment.)
waste, radioactive	Equipment and materials (from nuclear operations) which are radioactive and for which there is no further use. Wastes are generally classified as high-level (having radioactivity concentrations of hundreds of thousands of curies per gallon or cubic foot), low-level (in the range of 1 microcurie per gallon or cubic foot), or intermediate (between these extremes).

whole body counter	A device used to identify and measure the radiation in the body (body burden) of human beings and animals; it uses heavy shielding to keep out background radiation and ultrasensitive scintillation detectors and electronic equipment.
X-ray	A penetrating form of electromagnetic radiation emitted either when the inner orbital electrons of an excited atom return to their normal state (these are characteristic X-rays), or when a metal target is bombarded with high speed electrons (these are bremsstrahlung). X-rays are always nonnuclear in origin.

APPENDIX III

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w. Plutonium
x. Power From Radioisotopes
y. Radioactive Wastes
z. Radioisotopes and Life Processes
i. Reading Resources in Atomic Energy
ii. SNAP: Nuclear Space Reactors
iv. Sources of Nuclear Fuel
v. Synthetic Transuranium Elements
vi. Whole Body Counters
vii. Your Body and Radiation